

**4-PYRIMIDINAMINE DERIVATIVES, PHARMACEUTICAL
COMPOSITIONS AND RELATED METHODS**

Cross Reference to Related Application

- 5 This application claims priority from United States provisional application
Serial No. 60/223,791, filed August 8, 2000, which is hereby incorporated by
reference.

Field of the Invention

- 10 The present invention relates to novel neuroprotective 4-pyrimidineamine
derivatives, neuroprotective 4-pyrimidinamine and 2-pyridinamine compositions, and
methods of using same to prevent cell death after an ischemic event. The instant
compounds and compositions have particular importance in preventing neuronal cell
death and its resulting disorders.

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Background of the Invention

- Glutamate is the major fast excitatory neurotransmitter in the mammalian
central nervous system. It depolarizes neurons by opening three classes of ligand-gated
ion channels: AMPA, kainate, and NMDA receptors. Transient increases in synaptic
glutamate levels occur during normal excitatory transmission. However, excessive
increases in synaptic glutamate levels are toxic to neurons, and trigger the process of
neuronal cell death commonly referred to as glutamate excitotoxicity (Meldrum and
Garthwaite 1990). Glutamate excitotoxicity contributes to ischemia-induced brain
damage, epilepsy, and various chronic neurodegenerative diseases (Meldrum and
25 Garthwaite 1990).

- Of the three classes of glutamate-gated channels, specific overactivation of the
N-methyl-D-aspartate (NMDA) receptor is primarily responsible for triggering
excitotoxic neuron death in a variety of neuron types (Meldrum and Garthwaite 1990).
In animal stroke models, ischemia-induced brain damage can be largely alleviated by
pretreatment with the specific NMDA receptor antagonist, MK-801 (Park et al. 1988).
30 In many types of neurons, glutamate excitotoxicity is thought to result primarily from
excessive influx of calcium ions due to the high permeability of the NMDA receptor
for calcium (Schneggenburger et al. 1993). High intracellular calcium levels may lead

to overactivation of calcium-regulated enzymes such as nitric oxide synthase, phospholipases, proteases and kinases. Further, high intracellular calcium levels may mediate excitotoxicity.

Glutamate signaling through the NMDA receptor induces phosphorylation and activation of mitogen-activated protein kinases (MAPK) in primary neuronal cultures (Bading and Greenberg 1991; Xia et al. 1995). Animal models of ischemic brain injury suggest that increased activity of MAPK family members may mediate neuronal injury (Alessandrini et al. 1999; Yang et al. 1997). Deletion of Jnk3, a member of the JNK family of MAP kinases which is predominantly expressed in brain, protects

hippocampal neurons from kainic acid-induced excitotoxicity *in vivo*, although the role of the NMDA receptor in this form of toxicity is not clear (Yang et al. 1998). Specific inhibition of the upstream activating kinases of ERK1/2, (p44/42) MAP kinase, protects against neuronal damage due to focal cerebral ischemia (Alessandrini et al. 1999). In cultured primary hippocampal neurons, inhibition of the ERK1/2 (p44/42 MAPK) signaling pathway protects against neuron death induced by removal of kynurenate, a broad spectrum glutamate-receptor antagonist (Murray et al. 1998). Non-receptor-mediated glutamate-induced oxidative toxicity is also blocked by inhibition of the ERK1/2 signaling pathway (Stanciu et al. 2000). Collectively, these reports clearly indicate an important role for ERK1/2 MAPK signaling in glutamate-induced neuronal toxicity. However, it remains unclear as to what class of glutamate receptor can trigger the excitotoxic signaling cascade in which the ERK1/2 MAPK pathway is so critically involved.

Substantial evidence from the literature suggests that MEK (MAP Kinase or ERK Kinase, a threonine-tyrosine kinase activator of ERK1 and ERK2) inhibition is an effective neuroprotective strategy *in vivo* (Alessandrini et al. 1999; Hu and Wieloch 1994; Kindy 1993). These reports indicate that transient cerebral ischemia induces p42 MAP kinase phosphorylation in rodent brain. A selective inhibitor of MEK1/2, PD 098059, can block this induction in phosphorylation, and can reduce the extent of neuronal damage (Alessandrini et al. 1999). Primary neuronal culture literature also suggests that the MAP kinase pathway is relevant to excitotoxic damage *in vitro* (Bading and Greenberg 1991; Fiore et al. 1993; Kurino et al. 1995; Murray et al. 1998; Rosen et al. 1994; Xia et al. 1996). These reports indicate that glutamate signaling through its various ionotropic and/or metabotropic receptors results in p42/44 MAP

kinase activation. Increased p44/42 MAP kinase activation induces immediate early gene transcription (Xia et al. 1996) and is implicated in seizure activity-induced cell death of cultured hippocampal neurons (Murray et al. 1998).

The signaling pathways that link the NMDA receptor to p42/44 MAP kinase activation, or the downstream pathways which link p42/44 MAP kinase to delayed neurotoxicity, are not well understood. The upstream activators of p42/44 MAP kinases are MEK1 and MEK2 (Anderson et al. 1990; Crews, Alessandrini, and Erikson 1992; Zheng and Guan 1993). MEK1/2 are phosphorylated by the Raf family of kinases (Jaiswal et al. 1994; Moodie et al. 1993), which are activated by the Ras family of small GTP-binding proteins (Papin et al. 1995).

One candidate intermediate molecule that may couple NMDA receptor activation to the Ras/Raf/MEK/p42/44 MAPK signaling cascade is the calcium-dependent tyrosine kinase PYK2 (Lev et al. 1995). Increased intracellular calcium levels can activate PYK2, which can in turn activate MAP kinase signaling.

A second candidate intermediate that may link ion channel activation to MAP kinase signaling is calmodulin kinase (CaM-K). Two types of CaM-Ks are highly expressed in neurons, CaM-KII and CaM-KIV (Sakagami and Kondo 1993; Sola, Tusell, and Serratosa 1999). These protein kinases are activated upon binding of calcium and calmodulin, and they can regulate p38, JNK, and p42/44 MAP kinase activity (Enslen et al. 1996).

A third candidate intermediate molecule may be nitric oxide (NO). In cortical neurons, NMDA receptor coupling to NO production through PSD-95 is required for NMDA receptor-triggered neurotoxicity (Sattler et al. 1999). Increased NO production can also increase p42/44 MAP kinase activity (Lander et al. 1996).

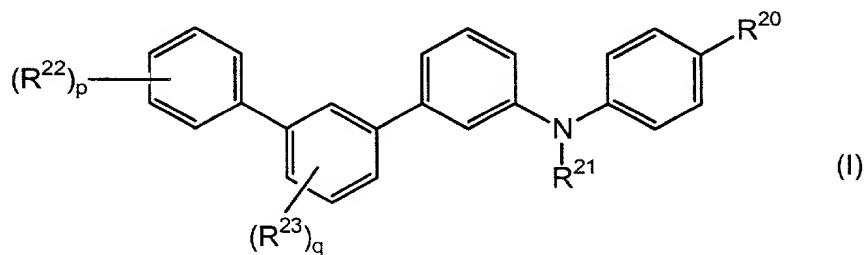
Molecules that are downstream of p42/44 MAP kinase include transcription factors such as CREB, Elk-1, c-Jun, and c-Fos (Vanhoutte et al. 1999). The p42/44 MAP kinase pathway can also induce phosphorylation of cytoskeletal components such as neurofilaments (Li et al. 1999a), regulate synapsin I-actin interactions (Jovanovic et al. 1996), phosphorylate myelin basic protein (Ahn et al. 1991), and regulate the secretion of amyloid precursor protein (Desdouits-Magnen et al. 1998). Therefore, there are many potential mediators of neurotoxicity downstream of p42/44 MAP kinase activation.

A detailed understanding of the signaling pathways that are activated downstream of glutamate receptor stimulation would be useful for determining efficient means of preventing hypoxia/ischemia-induced neuronal damage. Numerous attempts to study these pathways have been made toward this end. Lipton, U.S. Patent 5,506,231, describes a method of reducing damage to CNS neurons in a patient infected with human immunodeficiency virus by administration of a compound that antagonizes the NMDA receptor. This patent does not suggest neuroprotective effects by administration of a compound that modulates signal transduction pathway components downstream of the NMDA receptor. Maiese, U.S. Patent 5,519,035, describes Protein Kinase C inhibitors as neuroprotective from cerebral ischemia induced by nitric oxide administration. A model utilizing hippocampal neuronal cultures is described. Mahanthappa, WO 99/00117, describes compounds, including H89, that mimic the Hedgehog effects on the Patched-mediated signals, particularly inhibitors of protein kinase A (PKA) as neuroprotective agents. Liu, WO 99/58982, describes methods for identifying neuroprotective compounds that antagonize c-Jun N-termina Kinase (JNK) or mixed-lineage kinase (MLK) in neuronal cells, particularly HN33 hippocampal neuronal cells. Finally, Alessandrini, WO 99/34792, describes a mouse model of stroke in which focal cerebral ischemia is induced, and MEK1 inhibitors are administered to monitor neuroprotective effects.

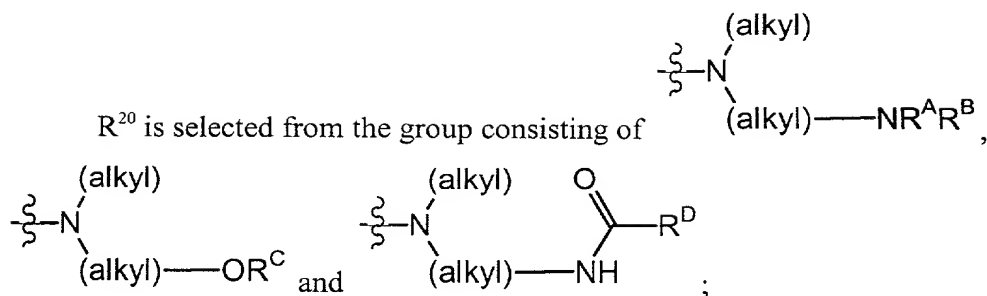
Despite what is known about glutamate receptor-mediated excitotoxicity, much remains to be learned about its mechanisms of action and compounds that can selectively inhibit the neuronal cell death it causes.

Summary of the Invention

The present invention is directed to novel neuroprotective 4-pyrimidineamine derivatives of the general formula (I)



wherein



wherein R^A and R^B are independently selected from hydrogen, alkyl, halogenated alkyl, amino, alkylamino, dialkylamino, aminoalkyl, alkylaminoalkyl, dialkylaminoalkyl, aryl, aralkyl, cycloalkyl, cycloalkyl-alkyl, heteroaryl, heteroaryl-alkyl, alkoxyalkyl, aryloxy, aryloxyalkyl and dehydroabietyl; wherein the aryl cycloalkyl, heteroaryl or heterocycloalkyl portion is optionally substituted with one or more substituents independently selected from halogen, alkyl, alkoxy, halogenated alkyl, amino, alkylamino, dialkylamino, arylamino, aralkylamino, amido, alkylamido, dialkylamido, arylamido, aralkylamido, azo, nitro, cyano, aryl, aralkyl, aryloxy, carboxy, alkoxycarbonyl, aryloxycarbonyl, alkylthio, arylthio, alkylsulfonylN(H), or alkylsulfonylN(alkyl);

alternatively R^A and R^B are taken together with the nitrogen atom to which they are bound to form a compound selected from the group heteroaryl and heterocycloalkyl; wherein the heteroaryl or heterocycloalkyl is optionally substituted with one or more substituents independently selected from halogen, alkyl, alkoxy, alkoxycarbonyl, halogenated alkyl, alkylcarbonyl, amino, alkylamino, dialkylamino, arylamino, azo, nitro or cyano;

R^C is selected from the group consisting of alkyl, aralkyl, alkylcarbonyl, arylcarbonyl, aralkylcarbonyl, (\pm)-N-benzoyl-aminoalkylcarbonyl or [3aS-(3a α ,4 β ,6a α)]-hexahydro-2-oxo-1H-thieno[3,4-d]imidazole-alkylcarbonyl;

R^D is selected from alkyl, aryl, aralkyl, (\pm)-N-benzoyl-aminoalkyl, [3aS-(3a α ,4 β ,6a α)]-hexahydro-2-oxo-1H-thieno[3,4-d]imidazole-alkyl or biphenyl; wherein the alkyl or aryl portion of the alkyl, aryl or aralkyl group is optionally substituted with one or more substituents independently selected from halogen, alkyl, alkoxy, amino, alkylamino, dialkylamino, azo, nitro, cyano, or trifluoromethyl);

R²¹ is selected from the group consisting of hydrogen, alkyl, aryl, aralkyl, alkylcarbonyl, arylcarbonyl and aralkylcarbonyl; wherein the aryl portion is optionally substituted with one or more substituents independently selected from halogen, alkyl, alkoxy, halogenated alkyl or nitro;

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p is an integer selected from 0 to 3;

q is an integer selected from 0 to 3;

R²² and R²³ are each independently selected from the group consisting of halogen, alkyl, alkoxy, amino, alkylamino, dialkylamino, nitro, cyano, carboxy, alkoxyrcrbonyl, aryoxycarbonyl, aminocarbonyl, alkylaminocarbonyl and dialkylaminocarbonyl;

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or a pharmaceutically acceptable salt thereof.

Illustrative of the invention is a pharmaceutical composition comprising a pharmaceutically acceptable carrier and any of the compounds of formula (I) described above. An illustration of the invention is a pharmaceutical composition made by mixing any of the compounds of formula (I) described above and a pharmaceutically acceptable carrier. Illustrating the invention is a process for making a pharmaceutical composition comprising mixing any of the compounds of formula (I) described above and a pharmaceutically acceptable carrier.

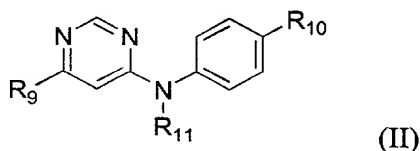
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Another example of the invention is the use of any of the compounds of formula (I) described herein in the preparation of a medicament for reducing ischemic death in a cell population in a subject in need thereof.

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This invention further provides a pharmaceutical composition comprising a pharmaceutically acceptable carrier and a compound having the general formula (II)



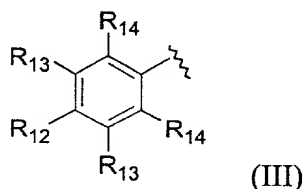
(II)

or a pharmaceutically acceptable salt thereof, wherein

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- (a) R_9 is selected from the group consisting of H, thienyl, furanyl, pyrrolyl, phenyl, substituted phenyl, pyridinyl, substituted pyridinyl, naphthyl, benzo[b]thien-2-yl, 2-benzofuranyl, pyrimidine and 2,4-(bismethoxyphenyl)-5-pyrimidinyl,

5 said substituted phenyl having the general formula (III)

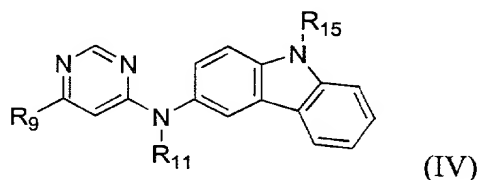


wherein (i) R_{12} is H, OH, lower alkylthio, alkoxy, alkylamine, dialkylamine, halogen-substituted lower alkyl, halogen substituted lower alkoxy, cyano, cyanoalkyl, phenyl, phenylalkoxy or substituted piperazinyl, N-(t-butoxy)carbamylalkyl, (ii) each R_{13} is independently H, NO_2 , alkoxy, alkylamino, dialkylamino, halogen-substituted lower alkyl, halogen-substituted lower alkoxy or phenyl, and (iii) each R_{14} is independently H, alkoxy, phenyloxy or phenylalkoxy;

- (b) R_{10} is selected from the group consisting of cyanoalkyl, alkylamino, dialkylamino, hydroxy-substituted alkylamino and hydroxy-substituted dialkylamino; and

- (c) R_{11} is H or lower alkyl.

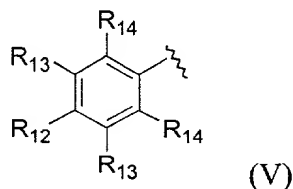
This invention also provides a pharmaceutical composition comprising a pharmaceutically acceptable carrier and a compound having the general formula (IV)



or a pharmaceutically acceptable salt thereof, wherein

- (a) R_9 is selected from the group consisting of H, thienyl, furanyl, pyrrolyl, phenyl, substituted phenyl, pyridinyl, substituted pyridinyl, naphthyl, benzo[b]thien-2-yl, 2-benzofuranyl, pyrimidine and 2,4-(bismethoxyphenyl)-5-pyrimidinyl,

5 said substituted phenyl having the general formula (V)



wherein (i) R_{12} is H, OH, lower alkylthio, alkoxy, alkylamine, dialkylamine, halogen-substituted lower alkyl, halogen substituted lower alkoxy, cyano, cyanoalkyl, phenyl, phenylalkoxy or substituted piperazinyl, N-(t-butoxy)carbamylalkyl, (ii) each R_{13} is independently H, NO_2 , alkoxy, alkylamino, dialkylamino, halogen-substituted lower alkyl, halogen-substituted lower alkoxy or phenyl, and (iii) each R_{14} is independently H, alkoxy, phenyloxy or phenylalkoxy;

(b) R_{11} is H or lower alkyl; and

(c) R_{15} is H or alkyl.

This invention further provides a method of reducing ischemic death in a cell population comprising contacting a cell in the cell population with a prophylactically effective amount of the compound contained in any of the instant pharmaceutical compositions.

This invention further provides a method for reducing neuronal cell death in response to a traumatic event comprising contacting the neuronal cell with a prophylactically effective amount of the compound contained in any of the instant pharmaceutical compositions prior to, during, or within a suitable time period following the traumatic event.

This invention still further provides a method for reducing neuronal cell death in response to a traumatic event in a subject, comprising administering to the subject a

prophylactically effective amount of any of the instant pharmaceutical compositions prior to, during, or within a suitable time period following the traumatic event.

Finally, this invention provides an apparatus for administering to a subject any of the instant pharmaceutical compositions comprising a container and the pharmaceutical composition therein, wherein the container has a device for delivering to the subject a prophylactic dose of the pharmaceutical composition.

Brief Description of the Figures

Figure 1. A: NMDA receptor-mediated functional intracellular calcium response. Filled square symbols represent the control, filled triangle symbols represent 100 μ M MK-80-1; B: [3 H]-MK-801 binding in differentiated P19 neurons.

Figure 2. A: P19 neuron viability experiment using Alamar Blue fluorescence measurements. B: Glutamate dose-response of death with alamar blue readings. Data presented as % control. C: MK-801 dose-dependent block.

Figure 3. A: Compound A, a p38 inhibitor, pretreatment dose response. B: U0126, a MEK1/2 inhibitor, pretreatment dose response.

Figure 4. A: U0126 does not block glutamate-induced calcium responses. B: U0126 does not block [3 H]-MK-801 binding in P19 neurons.

Figure 5. A: U0126 post treatment time course of efficacy. B: Compound A post treatment time course of efficacy.

Figure 6. A: U0126 does not inhibit staurosporine-induced toxicity. Filled square symbols represent no compound; filled triangle symbols represent 10 μ M U0126. B: U0126 does not block A23187-induced toxicity. C: U0126 does not affect basal P19 neuron viability.

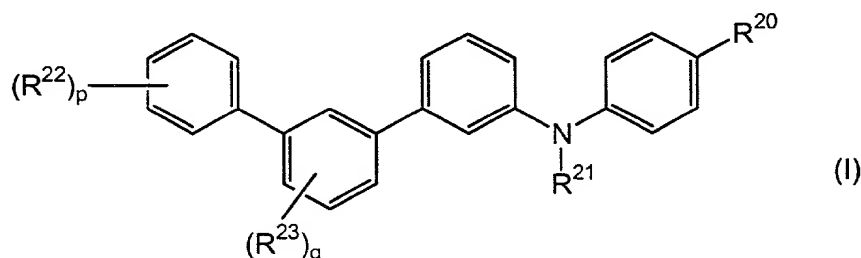
Figure 7. 2-pyridinamine and 4-pyrimidinamine compounds (listed by compound number) exhibit post-treatment delayed neuroprotection. Efficacy that is achieved at 2

hours post-glutamate treatment is equivalent to what is achieved when P19 neurons are pretreated with these compounds. This temporal profile matches that of the MEK inhibitor, U0126. Open, dotted bars represent pre treatment % NP; filled bars represent %NP 2 hours post treatment.

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Detailed Description of the Invention

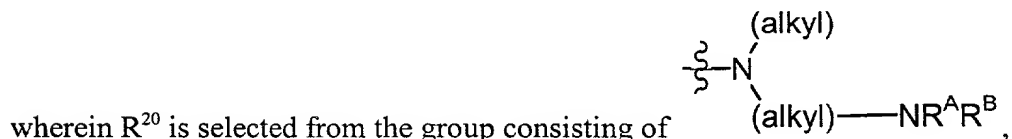
The present invention provides novel neuroprotective 4-pyrimidineamine derivatives of the general formula (I)



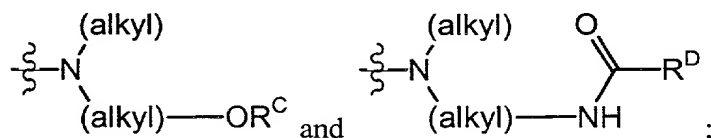
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or a pharmaceutically acceptable salt thereof, wherein R^{20} , R^{21} , p , q , R^{22} and R^{23} are as previously defined, useful in reducing ischemic death in a cell population.

In an embodiment of the present invention is a compound of the formula (I)



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R^A is selected from the group consisting of hydrogen, alkyl, aryl and aralkyl; wherein the aryl portion of any of the groups is optionally substituted with one to three substituents independently selected from halogen, lower alkyl, lower alkoxy, halogenated lower alkyl, amino, lower alkylamino, di(lower alkyl)amino, arylamino, aralkylamino, azo, nitro, cyano, aryl, aralkyl, aryloxy, carboxy, lower alkoxy-carbonyl, aryloxy-carbonyl, lower alkylthio and arylthio;

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R^B is selected from the group consisting of hydrogen, alkyl, halogenated lower alkyl, amino, lower alkylamino, di(lower alkyl)amino, amino-lower alkyl, lower alkyl-amino-lower alkyl, di(lower alkyl)amino-lower alkyl, aryl, aralkyl, cycloalkyl, cycloalkyl-lower alkyl, heteroaryl, heteroaryl-lower alkyl, lower alkoxy-lower alkyl,

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aryloxy, aryloxy-lower alkyl and dehydroabietyl; wherein the aryl, cycloalkyl, heteroaryl or heterocycloalkyl portion of any of the groups is optionally substituted with one to three substituents independently selected from halogen, lower alkyl, lower alkoxy, halogenated lower alkyl, amino, lower alkylamino, di(lower alkyl)amino, arylamino, aralkylamino, azo, nitro, cyano, aryl, aralkyl, aryloxy, carboxy, lower alkoxycarbonyl, aryloxycarbonyl, lower alkylthio and arylthio;

alternatively, R^A and R^B are taken together with the nitrogen atom to which they are bound to form a ring structure selected from the group consisting of heteroaryl and heterocycloalkyl; wherein the heteroaryl or heterocycloalkyl group is optionally substituted with one to two substituents independently selected from halogen, lower alkyl, lower alkoxy, lower alkoxycarbonyl, trifluoromethyl, lower alkylcarbonyl, amino, lower alkylamino, di(lower alkyl)amino, arylamino, azo, nitro or cyano.

R^C is selected from the group consisting of lower alkyl, aralkyl, lower alkylcarbonyl, arylcarbonyl, aralkylcarbonyl, (±)-N-benzoyl-amino-lower alkylcarbonyl and [3aS-(3α,4β,6α)]-hexahydro-2-oxo-1H-thieno[3,4-d]imidazole-lower alkylcarbonyl;

R^D is selected from the group consisting of alkyl, aryl, aralkyl, (±)-N-benzoyl-amino-lower alkyl, [3aS-(3α,4β,6α)]-hexahydro-2-oxo-1H-thieno[3,4-d]imidazole-lower alkyl and biphenyl; wherein the aryl portion of the aryl or aralkyl group is optionally substituted with one to two substituents independently selected from halogen, lower alkyl, lower alkoxy, amino, lower alkylamino, di(lower alkyl)amino, azo, nitro, cyano or trifluoromethyl);

R²¹ is selected from the group consisting of hydrogen, lower alkyl, aryl, aralkyl, lower alkylcarbonyl, arylcarbonyl and aralkylcarbonyl (wherein the aryl portion of the aryl, aralkyl, arylcarbonyl or aralkylcarbonyl group is optionally substituted with one to two substituents independently selected from halogen, lower alkyl, lower alkoxy or trifluoromethyl);

p is an integer from 0 to 2;

q is an integer form 0 to 2;

R²² and R²³ are each independently selected from the group consisting of halogen, lower alkyl, lower alkoxy, amino, lower alkylamino, di(lower alkyl)amino, nitro, cyano, carboxy, lower alkoxycarbonyl, phenyloxycarbonyl, aminocarbonyl, lower alkylaminocarbonyl and di(lower alkyl)aminocarbonyl;

or a pharmaceutically acceptable salt thereof.

In an embodiment of the present invention R^{20} is $\begin{array}{c} \text{(alkyl)} \\ \diagup \\ \text{---} \text{N} \text{---} \\ \diagdown \\ \text{(alkyl)} \end{array} \text{---} \text{NR}^A \text{R}^B$.

5 Preferably, R^A is selected from the group consisting of hydrogen, lower alkyl and aralkyl. More preferably, R^A is selected from the group consisting of hydrogen, methyl, ethyl and benzyl. More preferably still, R^A is selected from the group consisting of hydrogen, methyl and benzyl. Most preferably, R^A is selected from the group consisting of hydrogen and methyl.

10 Preferably, R^B is selected from the group consisting of hydrogen, lower alkyl, halogenated lower alkyl, aralkyl, substituted aralkyl (wherein the substituents on the aralkyl are one to three independently selected from halogen, alkyl, alkoxy or trifluoromethyl), alkoxyalkyl, cycloalkyl-alkyl, dehydroabietyl, dialkylaminoalkyl,
15 biphenyl, heteroaryl, substituted heteroaryl (wherein the substituents on the heteroaryl group are one to two independently selected from halogen or lower alkyl), heteroaryl-alkyl, aryloxyalkyl and alkoxycaronylalkyl.

More preferably, R^B is selected from the group consisting of hydrogen, methyl, ethyl, propyl, n-butyl, benzyl, phenylethyl, methoxypropyl, cyclohexylmethyl, 3-
20 chlorobenzyl, 2,4-dimethoxybenzyl, 2-ethoxybenzyl, 2,5-difluorobenzyl, dehydroabietyl, 3,4-dimethoxybenzyl, diethylaminoethyl, 4-bromo-2-pyridyl, dimethylaminoethyl, 4-biphenyl, 2-furanylmethyl, 3-iodobenzyl, 2,2,2-trifluoroethyl, 3,4-difluorobenzyl, 2-thienylethyl, 3,5-dimethyl-2-pyridyl, 2-(ethoxy)acetyl, 2-methoxybenzyl, 4-bromobenzyl, 3,5-ditrifluoromethylbenzyl, 3-methoxyphenylethyl,
25 3,4,5-trimethoxybenzyl, 4-methoxyphenylethyl, 4-imidazolylethyl, 2-trifluoromethylbenzyl, 3-methoxybenzyl, 3-methylbenzyl, 3,5-dimethoxybenzyl, 2-bromobenzyl, 4-fluorobenzyl, 1-naphthylmethyl, phenoxyethyl, 4-trifluoromethylbenzyl, 3-pyridyl, 2-methylbenzyl, 2-fluorobenzyl and 3,4-dimethoxyphenylethyl.

30 More preferably still, R^B is selected from the hydrogen, methyl and benzyl; and R^B is selected from the group consisting of methyl, methoxypropyl, cyclohexylmethyl,

3-chlorobenzyl, 2,5-difluorobenzyl, phenylethyl, 4-bromo-2-pyridyl, dimethylaminoethyl, n-butyl, 2-furanylmethyl, 3,4-difluorobenzyl, 2-thienylethyl, 4-bromobenzyl, 3-methoxyphenylethyl, 3,4,5-trimethoxybenzyl, benzyl, 3-methylbenzyl and phenoxyethyl.

- 5 More preferably still, R^B is selected from the group consisting of methyl, methoxypropyl, 2,5-difluorobenzyl, 3,4difluorobenzyl, 4-bromobenzyl, 3,4,5-trimethoxybenzyl, benzyl, 3-methylbenzyl and n-butyl.

Most preferably, R^B is methyl.

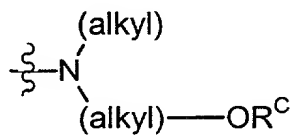
- 10 In an embodiment of the present invention, R^A and R^B are taken together with the nitrogen atom to which they are bound to form a ring structure selected from the group consisting of N-pyrrolidinyl, N-morpholinyl, N-imidazolyl, N-1,2,3,4-tetrahydroisoquinolinyl, N-hexamethyleneimine and N-(4-tertiarybutoxycarbonyl)piperazinyl.

- 15 Preferably, R^A and R^B are taken together with the nitrogen atom to which they are bound to form a ring structure selected from the group consisting of N-morpholinyl and N-(4-tertiarybutoxycarbonyl)piperazinyl.

More preferably, R^A and R^B are taken together with the nitrogen atom to which they are bound to form N-morpholinyl.

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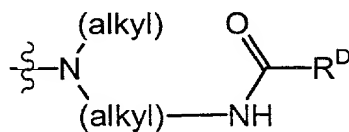
In an embodiment of the present invention R²⁰ is



Preferably R^C is selected from the group consisting of aralkylcarbonyl, (±)-N-benzoyl-2-aminoalkylcarbonyl and [3aS-(3α,4β,6α)]-hexahydro-2-oxo-1H-

- 25 thieno[3,4-d]imidazole-alkylcarbonyl. More preferably, R^C is selected from the group consisting of benzoyl, (±)-N-benzoyl-2-aminopropionoyl and [3aS-(3α,4β,6α)]-hexahydro-2-oxo-1H-thieno[3,4-d]imidazole-4-pentanoyl.

In an embodiment of the present invention R²⁰ is



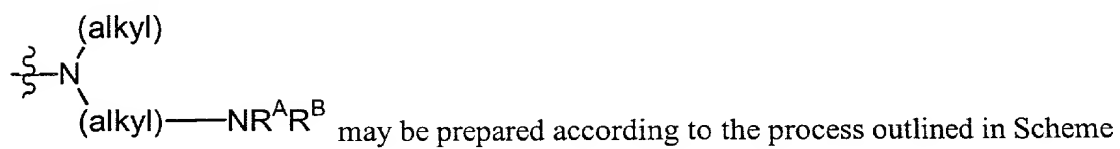
Preferably, R^D is selected from the group consisting of (\pm)-N-benzoyl-2-aminoalkyl, [3aS-(3 α ,4 β ,6 α)]-hexahydro-2-oxo-1H-thieno[3,4-d]imidazole-alkyl, alkyl, aryl, substituted aryl (where the substituents on the aryl are independently selected from azo, nitro, halogen, alkoxy, trifluoromethyl), biphenyl, aralkyl and substituted aralkyl (wherein the alkyl portion of the aralkyl group is substituted with a substituent selected from halogen). More preferably, R^D is selected from the group consisting of (\pm)-N-benzoyl-2-aminoethyl, [3aS-(3 α ,4 β ,6 α)]-hexahydro-2-oxo-1H-thieno[3,4-d]imidazole-but-4-yl, 1-chloro-1-phenyl-methyl, 3-azo-6-nitrophenyl, pentadecanyl, 4-biphenyl, 4-butoxyphenyl, 4-trifluoromethylphenyl, 3-fluorophenyl and propyl.

In an embodiment of the present invention R^{21} is selected from the group consisting of hydrogen, alkyl, aralkyl, alkylcarbonyl and arylcarbonyl, wherein the aryl group is optionally substituted with a substituent selected from halogen and trifluoromethyl. Preferably, R^{21} is selected from the group consisting of hydrogen, ethyl, benzyl, propylcarbonyl, 3-fluorophenylcarbonyl and 4-trifluoromethylphenylcarbonyl. More preferably, R^{21} is hydrogen.

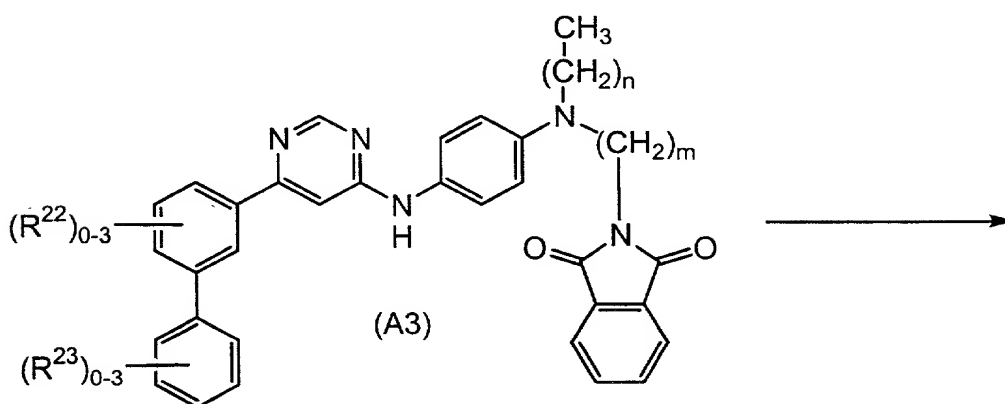
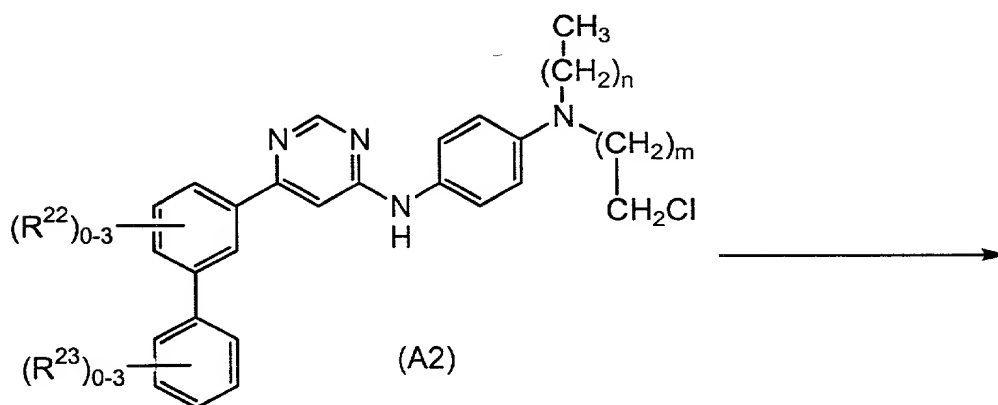
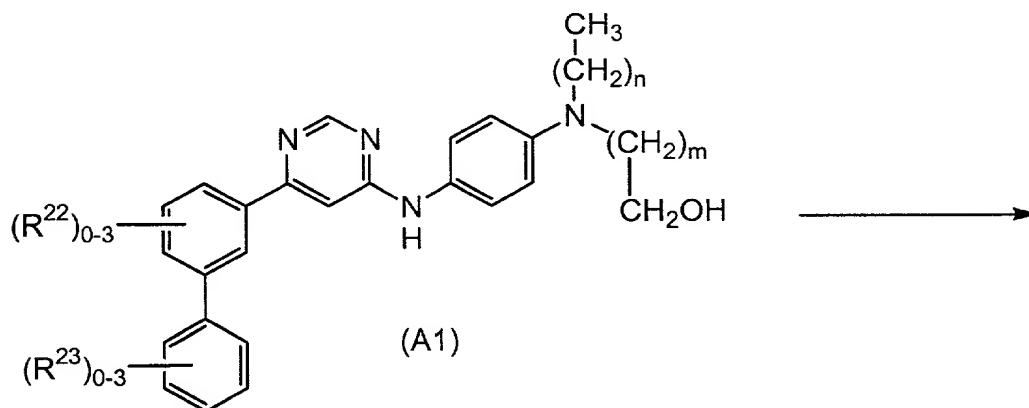
In an embodiment of the present invention p is an integer from 0 to 2. Preferably p is an integer from 0 to 1. In an embodiment of the present invention q is an integer from 0 to 2. Preferably q is an integer from 0 to 1.

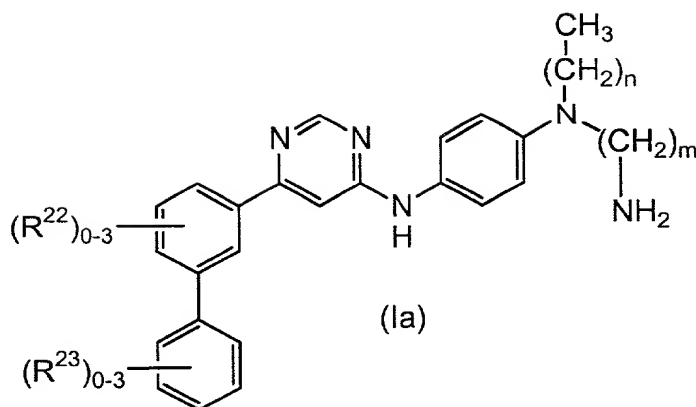
In an embodiment of the present invention, R^{22} and R^{23} are each independently selected from the group consisting of halogen, lower alkyl, lower alkoxy, amino, lower alkylamino, di(lower alkyl)amino, nitro, cyano, carboxy, lower alkoxy carbonyl, phenyloxycarbonyl, aminocarbonyl, lower alkylaminocarbonyl and di(lower alkyl)aminocarbonyl.

Compounds of formula (I) wherein R^{20} is selected from the group consisting of



1 and 2.





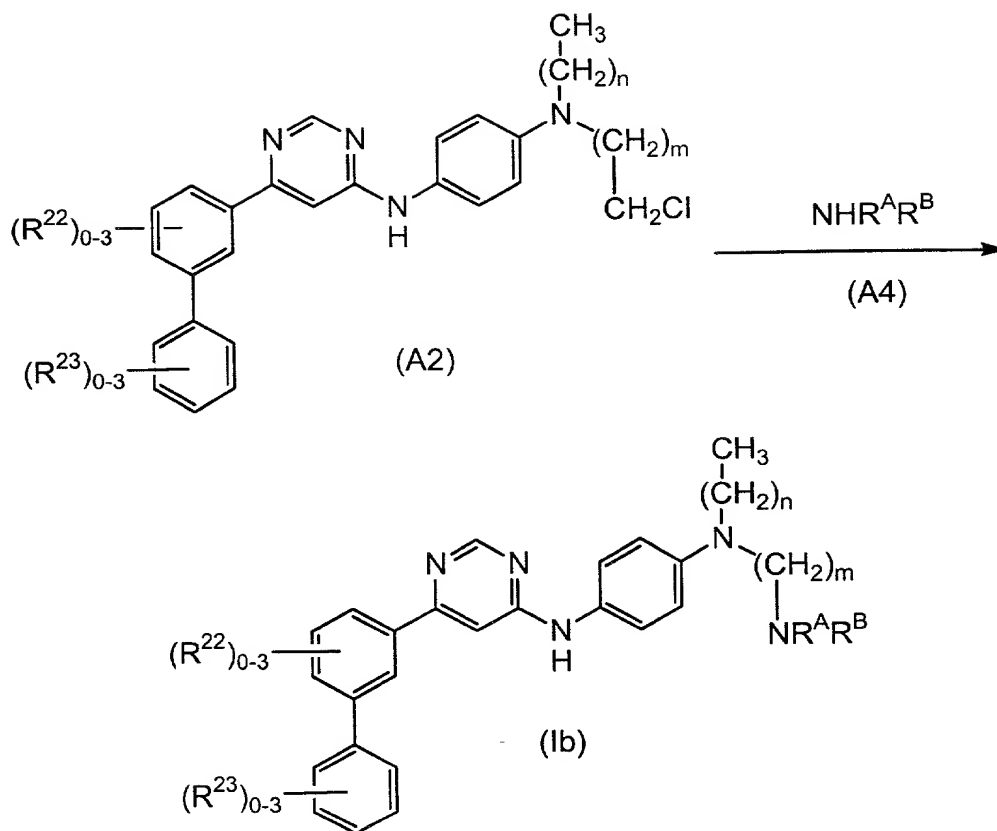
Scheme 1

More particularly, a suitably substituted compound of formula (A1), wherein n and m are each independently an integer selected from 0 to 7, a known compound or compound prepared by known methods (for example wherein n and m are each 1, the compound may be purchased from BioFocus, PCC (UK)), is reacted with thionyl chloride, in a halogenated organic solvent such dichloromethane, chloroform, and the like, under anhydrous conditions, to yield the corresponding compound of formula (A2).

The compound of formula (A2) is reacted with potassium phthalimide, in an organic solvent such as N-methyl-pyrrolidinone (NMP), N, N-dimethylformamide (DMF), and the like, under anhydrous conditions, to yield the corresponding compound of formula (A3).

The compound of formula (A3) is reacted with hydrazine monohydrate, in an organic solvent such as ethanol, methanol, isopropanol, and the like, at reflux temperature, to yield the corresponding compound of formula (Ia).

Compounds of formula (I) wherein R^A and/or R^B are other than hydrogen may be prepared according to the process outlined in Scheme 2.

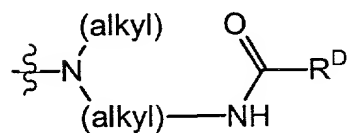


Scheme 2

- Accordingly, a suitably substituted compound of formula (A2), prepared as in
- 5 Scheme 1 is reacted with suitably substituted primary, secondary or cyclic amine, a compound of formula (A4), in an organic solvent such as N-methyl-pyrrolidinone (NMP), N,N-dimethylformamide (DMF), and the like, at an elevated temperature in the range of about 100-150°C, preferably at a temperature in the range of about 100-135°C, to yield the corresponding compound of formula (Ib).

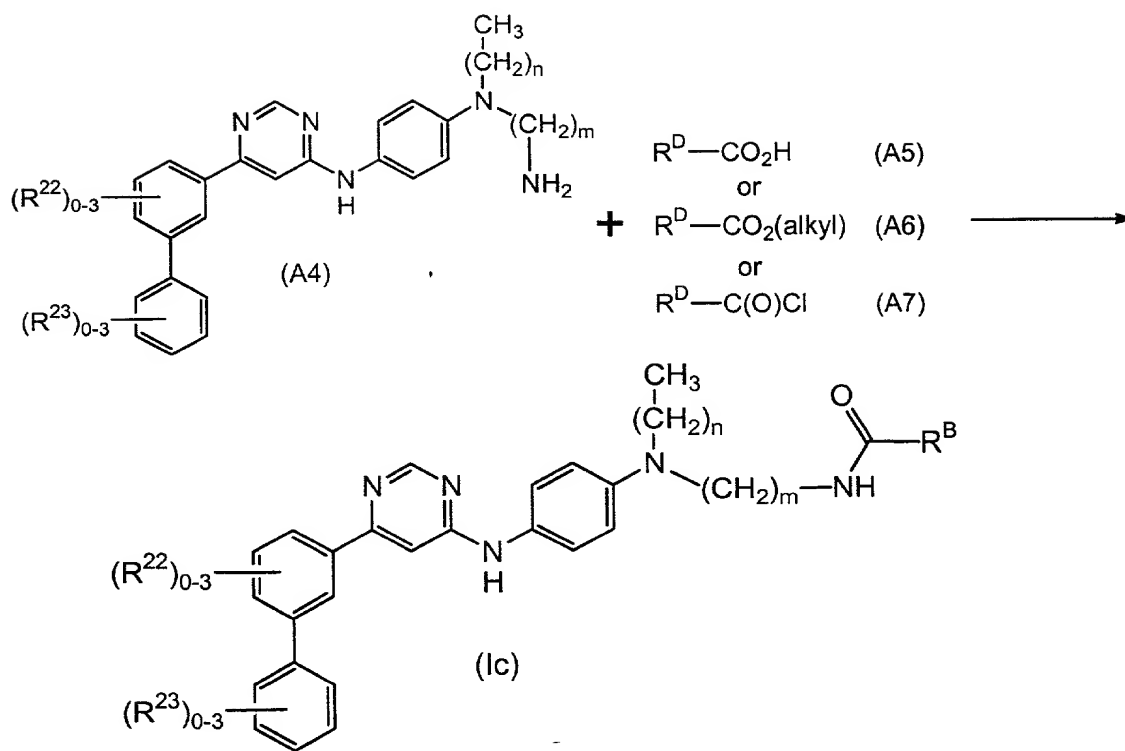
10

Compound of formula (I) wherein R^{20} is selected from the group consisting of



may be prepared according to the process outlined in

Scheme 3.



Scheme 3

Accordingly, a suitably substituted compound of formula (A4), prepared as in Scheme 1, is reacted with a suitably substituted acid, a compound of formula (A5), a suitably substituted alkyl ester, a compound of formula (A6) or a suitably substituted acid chloride, a compound of formula (A7), to yield the corresponding compound of formula (Ic).

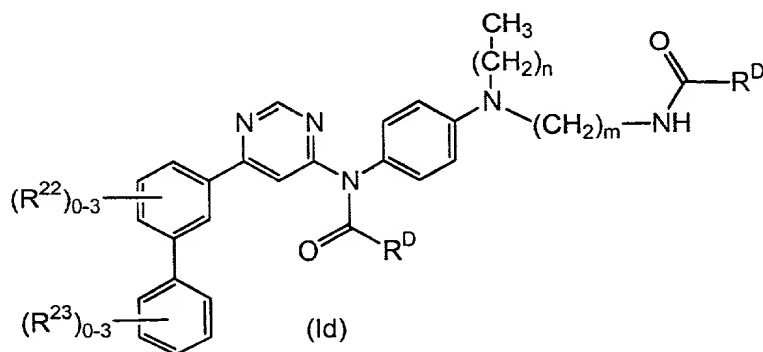
Wherein the compound of formula (A4) is reacted with an acid, a compound of formula (A5), the reaction is carried out in an organic solvent such as NMP, DMF, and the like, in the presence of a coupling catalyst such as O-benzoyltriazol-1-yl-N,N,N',N'-tetramethyluronium hexafluorophosphate (HBTU), O-(7-azabenzotriazol-1-yl)-N,N,N',N'-tetramethyluronium hexafluorophosphate (HATU), and the like, in the presence of a tertiary amine such as triethylamine (TEA), diisopropylethylamine (DIPEA), pyridine, and the like, to yield the corresponding compound of formula (Ic).

Wherein the compound of formula (A4) is reacted with an alkyl ester, a compound of formula (A6), the reaction is carried out in an organic solvent such as dioxane, tetrahydrofuran (THF), toluene, and the like, in the presence of a TEA, DIPEA, pyridine, and the like, to yield the corresponding compound of formula (Ic).

Wherein the compound of formula (A4) is reacted with an acid chloride, a compound of formula (A7), the reaction is carried out in an organic solvent such as dioxane, THF, toluene, and the like, in the presence of a tertiary amine such as TEA, DIPEA, pyridine, and the like, to yield the corresponding compound of formula (Ic).

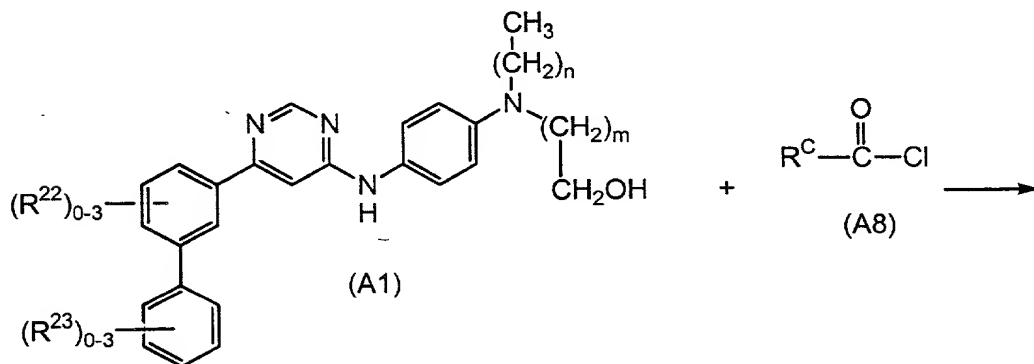
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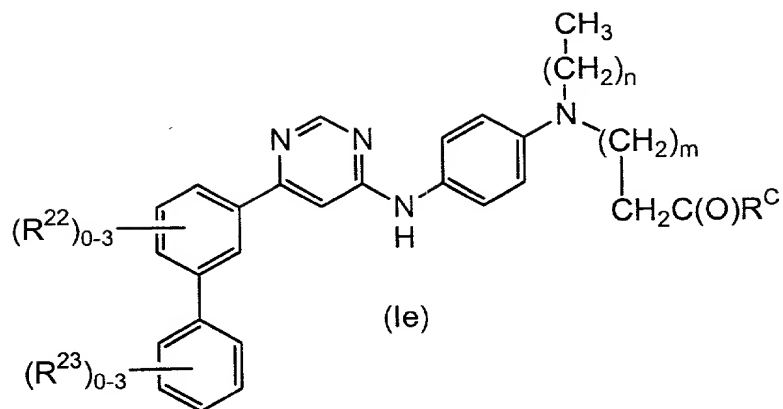
For compounds of formula (I) wherein R^{21} is selected from the group consisting of alkylcarbonyl, arylcarbonyl or aralkylcarbonyl, and wherein R^D is selected from the group consisting of alkyl, aryl or aralkyl, the compound of formula (A4) may be reacted with a suitably substituted compound of formula (A5) or (A7), preferably with two or more equivalents of the compound of formula (A5) or (A7), to yield the corresponding compound of formula (Id).



Compounds of formula (I) wherein R^{20} is selected from the group consisting of

15 $\begin{matrix} \text{(alkyl)} \\ | \\ \text{---}N\text{---} \\ | \\ \text{(alkyl)} \end{matrix} \text{---}OR^C$ may be prepared according to the process outlined in Scheme 4.

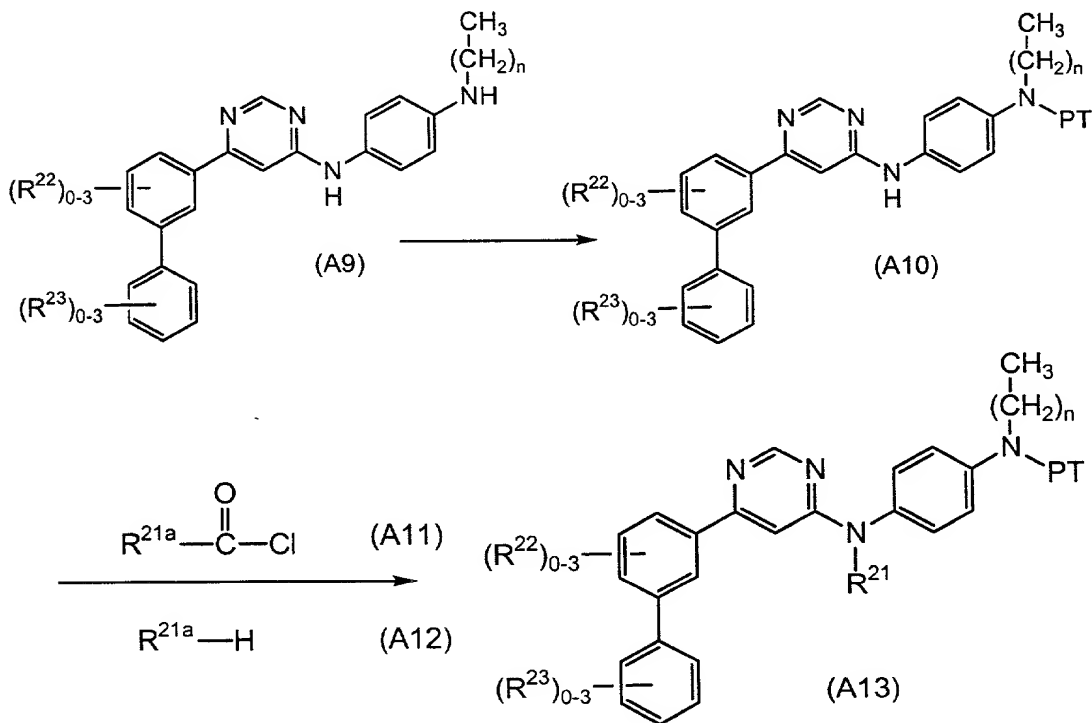


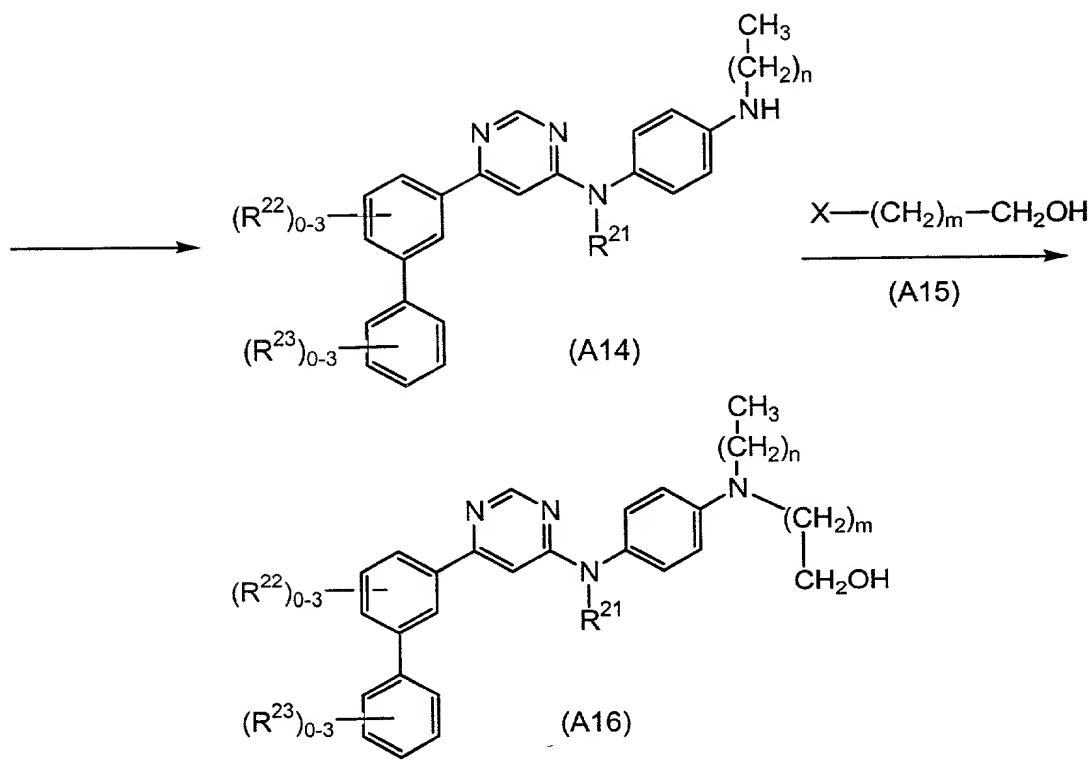


Scheme 3

Accordingly, a suitably substituted compound of formula (A1), is reacted with a suitably substituted acid chloride, a compound of formula (A8), in an organic solvent such as toluene, dioxane, THF, and the like, in the presence of a tertiary amine such as TEA, DIPEA, pyridine, and the like, optionally at an elevated temperature in the range of about 50-100°C, to yield the corresponding compound of formula (Ie).

Compounds of formula (I) wherein R²¹ is other than hydrogen may be prepared according to the process outlined in Scheme 5.





Scheme 5

More particularly, a compound of formula (A9), a known compound or
 5 compound prepared by known methods, is reacted with a protecting reagent such as 2-
 (tertiarybutoxycarbonyloxyimino)-2-phenylacetonitrile chloride (BOC-ON), and the
 like, in an organic solvent such as chloroform, methylene chloride, and the like, to yield
 the corresponding compound of formula (A10), wherein PT is the corresponding
 protecting group, such as tertiarybutoxycarbonyl, and the like.

10 The compound of formula (A10) is reacted with a suitably substituted acid
 chloride of formula (A11), wherein R^{21a} is alkyl, aryl or aralkyl, or with a suitably
 substituted acid of formula (A12), to yield the corresponding compound of formula
 (A13).

15 Wherein the compound of formula (A10) is reacted with a suitably substituted
 acid chloride of formula (A11), the reaction is carried out in an organic solvent such as
 methylene chloride, chloroform, and the like, in the presence of an organic amine such
 as N-methyl-morpholine, DIPEA, TEA, pyridine, and the like, to yield the
 corresponding compound of formula (A13).

20 Wherein the compound of formula (A10) is reacted with a suitably substituted
 acid of formula (A12), the reaction is carried out in an organic solvent such as N,N-

dimethylformamide (DMF), NMP, and the like, in the presence of an activating agent such as carbonyldiimidazole, cyclohexylcarbodiimine, and the like, to yield the corresponding compound of formula (A13).

The compound of formula (A13) is deprotected under standard deprotection conditions, known to one skilled in the art (for example, where the protecting group is tertiarybutoxycarbonyl, the deprotection is carried out in an organic solvent such as methylene chloride, chloroform, and the like, in the presence of an acid such as trifluoroacetic acid, hydrochloric acid, and the like), to yield the corresponding compound of formula (A14).

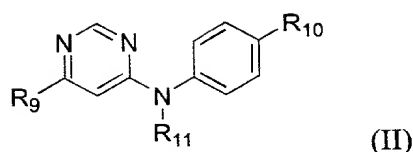
The compound of formula (A14) is then reacted with a halo alcohol, a compound of formula (A15), wherein X is a halogen such as Br, Cl, I, F, (for example 2-bromoethanol), in an organic solvent such as ethanol, methanol, and the like, optionally at reflux temperature, to yield the corresponding compound of formula (A16).

One skilled in the art will recognize that the compound of formula (A16) is then substituted for the compound of formula (A1) in Scheme 1 or Scheme 4, and reacted according to the process outlined in Scheme 1, 2, 3 and/or 4 to yield the desired corresponding compound of formula (I).

The present invention further provides pharmaceutical compositions comprising a pharmaceutically acceptable carrier and a compound of formula (I).

The present invention further provides a method for reducing ischemic death in a cell population in a subject in need thereof, comprising administering to the cell or the subject a therapeutically or prophylactically effective amount of one or more compounds of formula (I) or a pharmaceutical composition containing one or more compounds of formula (I).

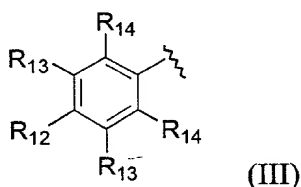
The invention also provides a pharmaceutical composition comprising a pharmaceutically acceptable carrier and a compound having the general formula (II)



or a pharmaceutically acceptable salt thereof, wherein

- (a) R_9 is selected from the group consisting of H, thienyl, furanyl, pyrrolyl, phenyl, substituted phenyl, pyridinyl, substituted pyridinyl, naphthyl, benzo[b]thien-2-yl, 2-benzofuranyl, pyrimidine and 2,4-(bismethoxyphenyl)-5-pyrimidinyl,

said substituted phenyl having the general formula (III)



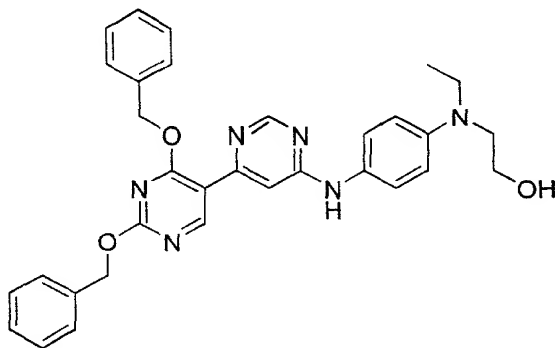
wherein (i) R_{12} is H, OH, lower alkylthio, alkoxy, alkylamine, dialkylamine, halogen-substituted lower alkyl, halogen substituted lower alkoxy, cyano, cyanoalkyl, phenyl, phenylalkoxy or substituted piperazinyl, N-(t-butoxy)carbonylalkyl, (ii) each R_{13} is independently H, NO_2 , alkoxy, alkylamino, dialkylamino, halogen-substituted lower alkyl, halogen-substituted lower alkoxy or phenyl, and (iii) each R_{14} is independently H, alkoxy, phenyloxy or phenylalkoxy;

- (b) R_{10} is selected from the group consisting of cyanoalkyl, alkylamino, dialkylamino, hydroxy-substituted alkylamino and hydroxy-substituted dialkylamino; and
- (c) R_{11} is H or lower alkyl.

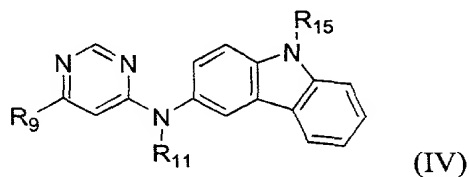
In one embodiment of the instant pharmaceutical composition, R_9 is substituted phenyl. In another embodiment, R_{11} is H and R_{10} is dialkylamino or hydroxy-substituted dialkylamino.

In the preferred embodiment of the instant pharmaceutical composition, the compound contained therein is selected from the following group, whose structures are set forth in the Experimental Details:

- 5 N1,N1-dimethyl-N4-[6-[4-(phenylmethoxy)phenyl]-4-pyrimidinyl]-1,4-benzenediamine;
- N1-(6-[1,1'-biphenyl]-3-yl-4-pyrimidinyl)-N4,N4-dimethyl-1,4-benzenediamine;
- N1-[6-[3,5-bis(trifluoromethyl)phenyl]-4-pyrimidinyl]-N4,N4-dimethyl-1,4-benzenediamine;
- 10 2-[[4-[(6-[1,1'-biphenyl]-3-yl-4-pyrimidinyl)amino]phenyl]ethylamino]-ethanol;
- 2-[[4-[(6-benzo[b]thien-2-yl-4-pyrimidinyl)amino]phenyl]ethylamino]-ethanol;
- 2-[ethyl[4-[[6-[4-(trifluoromethoxy)phenyl]-4-pyrimidinyl]amino]phenyl]amino]-ethanol; and
- 15 2-{[4-(2',4'-bis-benzyoxy-[4,5']bipyrimidyl-6-ylamino)-phenyl]-ethyl-amino}-ethanol, the compound having the structure shown below.



- The invention also provides a pharmaceutical composition comprising a
- 20 pharmaceutically acceptable carrier and a compound having the general formula (IV)

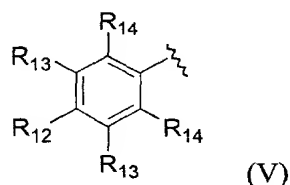


or a pharmaceutically acceptable salt thereof, wherein

- (a) R_9 is selected from the group consisting of H, thienyl, furanyl, pyrrolyl, phenyl, substituted phenyl, pyridinyl, substituted pyridinyl, naphthyl, benzo[b]thien-2-yl, 2-benzofuranyl, pyrimidine and 2,4-(bismethoxyphenyl)-5-pyrimidinyl,

5

said substituted phenyl having the general formula (V)



- wherein (i) R_{12} is H, OH, lower alkylthio, alkoxy, alkylamine, dialkylamine, halogen-substituted lower alkyl, halogen substituted lower alkoxy, cyano, cyanoalkyl, phenyl, phenylalkoxy or substituted piperazinyl, N-(t-butoxy)carbamylalkyl, (ii) each R_{13} is independently H, NO_2 , alkoxy, alkylamino, dialkylamino, halogen-substituted lower alkyl, halogen-substituted lower alkoxy or phenyl, and (iii) each R_{14} is independently H, alkoxy, phenoxy or phenylalkoxy;
- 10
- (b) R_{11} is H or lower alkyl; and
- (c) R_{15} is H or alkyl.
- 15

Unless specified otherwise, as used herein, the term "alkyl" refers to a saturated straight, branched or cyclic substituent consisting solely of carbon and H. Preferably, the alkyl chain comprises one to twenty carbon atoms, more preferably, one to fifteen carbon atoms, more preferably still, one to eight carbon atoms. Lower alkyl refers to an alkyl containing 1 to 4 carbon atoms.

20

The term "alkenyl" refers to an unsaturated straight, branched or cyclic substituent consisting solely of carbon and H that contains at least one double bond.

- 25 The term "alkynyl" refers to an unsaturated straight, branched or cyclic substituent consisting solely of carbon and H that contains at least one triple bond.

The term "alkoxy" refers to O-alkyl where alkyl is as defined. The term "alkylthio" refers to S-alkyl where alkyl is as defined and the alkylthio group is bound through the S atom.

An acidic alkyl is a carbon chain with a terminal COOH group. As used herein, the term "alkylamino" shall mean an alkyl substituted amine group. Similarly, the term "dialkylamino" shall mean an amino group substituted with two independently selected alkyl groups. The term "hydroxy substituted dialkylamino" shall refer to a

- 5 dialkylamino group wherein either or both of the alkyl groups are independently substituted with a hydroxy group, independently at any of the carbon atoms of the alkyl group(s).

The term "halo" means fluoro, chloro, bromo and iodo.

The symbol "Ph" or "PH" refers to phenyl.

- 10 As used herein, unless otherwise noted, "aryl" shall refer to unsubstituted carbocyclic aromatic groups such as phenyl, naphthyl, and the like.

As used herein, unless otherwise noted, "aralkyl" shall mean any lower alkyl group substituted with an aryl group such as phenyl, naphthyl and the like. For example, benzyl, phenylethyl, phenylpropyl, naphthylmethyl, and the like.

- 15 As used herein, unless otherwise noted, "heteroaryl" shall denote any five or six membered monocyclic aromatic ring structure containing at least one heteroatom selected from the group consisting of O, N and S, optionally containing one to three additional heteroatoms independently selected from the group consisting of O, N and S; or a nine or ten membered bicyclic aromatic ring structure containing at least one heteroatom selected
20 from the group consisting of O, N and S, optionally containing one to four additional heteroatoms independently selected from the group consisting of O, N and S. The heteroaryl group may be attached at any heteroatom or carbon atom of the ring such that the result is a stable structure.

- Examples of suitable heteroaryl groups include, but are not limited to, pyrrolyl,
25 furyl, thienyl, oxazolyl, imidazolyl, purazolyl, isoxazolyl, isothiazolyl, triazolyl, thiadiazolyl, pyridyl, pyridazinyl, pyrimidinyl, pyrazinyl, pyranyl, furazanyl, indoliziny, indolyl, isoindoliny, indazolyl, benzofuryl, benzothienyl, benzimidazolyl, benzthiazolyl, purinyl, quinoliziny, quinoliny, isoquinoliny, isothiazolyl, cinnoliny, phthalazinyl, quinazoliny, quinoxaliny, naphthyridiny, pteridiny, and the like. Preferred heteroaryl
30 groups include furanyl, thienyl, imidazolyl, pyridyl and isoquinolonyl.

As used herein, the term "heterocycloalkyl" shall denote any four to eight membered, preferably five to seven membered monocyclic, saturated or partially unsaturated ring structure containing at least one heteroatom selected from the group

consisting of O, N and S, optionally containing one to three additional heteroatoms independently selected from the group consisting of O, N and S; or a nine to ten membered saturated, partially unsaturated or partially aromatic bicyclic ring system containing at least one heteroatom selected from the group consisting of O, N and S, optionally containing one to four additional heteroatoms independently selected from the group consisting of O, N and S. The heterocycloalkyl group may be attached at any heteroatom or carbon atom of the ring such that the result is a stable structure.

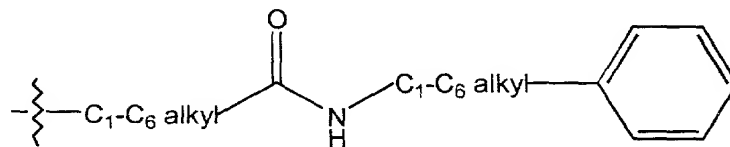
Examples of suitable heteroaryl groups include, but are not limited to, pyrrolinyl, pyrrolidinyl, dioxalanyl, imidazoliny, imidazolidinyl, pyrazoliny, pyrazolidinyl, piperidinyl, dioxanyl, morpholinyl, dithianyl, thiomorpholinyl, piperazinyl, trithianyl, indolinyl, chromenyl, 3,4-methylenedioxyphenyl, 2,3-dihydrobenzofuryl, 1,2,3,4-tetrahydroisoquinolinyl, hexamethyleneimine, and the like. Preferred heterocycloalkyl groups include pyrrolidinyl, morpholinyl, 1,2,3,4-tetrahydroisoquinolinyl, hexamethyleneimine and piperazinyl.

When a particular group is "substituted" (e.g., aryl, heterocycloalkyl, heteroaryl, and the like), that group may have one or more substituents, preferably from one to five substituents, more preferably from one to three substituents, most preferably from one to two substituents, independently selected from the list of substituents.

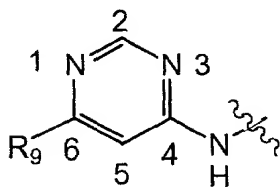
With reference to substituents, the term "independently" means that when more than one of such substituents is possible, such substituents may be the same or different from each other.

Under standard nomenclature used throughout this disclosure, the terminal portion of the designated side chain is described first, followed by the adjacent functionality toward the point of attachment. Thus, for example, a

"phenylC₁-C₆alkylaminocarbonylC₁-C₆alkyl" substituent refers to a group of the formula



For the purposes of this invention, the pyrimidine ring system shall have the following numbering.



The compounds contained in the instant pharmaceutical compositions are exemplified in the Experimental Details section below. Compounds of formula (II) and (IV) are commercially available from BioFocus PCC (UK) as part of a chemical library. Alternatively, the compounds of formula (II) and (IV) exemplified below may be prepared using known methods.

As used herein, the phrase "pharmaceutically acceptable salt" means a salt of the free base which possesses the desired pharmacological activity of the free base and which is neither biologically nor otherwise undesirable. These salts may be derived from inorganic or organic acids. Examples of inorganic acids are hydrochloric acid, nitric acid, hydrobromic acid, sulfuric acid, and phosphoric acid. Examples of organic acids are acetic acid, propionic acid, glycolic acid, lactic acid, pyruvic acid, malonic acid, succinic acid, malic acid, maleic acid, fumaric acid, tartaric acid, citric acid, benzoic acid, cinnamic acid, mandelic acid, methanesulfonic acid, ethanesulfonic acid, p-toluenesulfonic acid, methyl sulfonic acid, salicylic acid and the like.

The pharmaceutical compositions of the instant invention may be prepared according to conventional pharmaceutical techniques. The pharmaceutically acceptable carrier therein may take a wide variety of forms depending on the form of preparation desired for administration, such as systemic administration, including but not limited to intravenous, oral, nasal or parenteral. In preparing the compositions in oral dosage form, any of the usual pharmaceutical carriers may be employed, such as water, glycols, oils, alcohols, flavoring agents, preservatives, coloring agents, syrup and the like in the case of oral liquid preparations (for example, suspensions, elixirs and solutions), or carriers such as starches, sugars, diluents, granulating agents, lubricants, binders,

disintegrating agents and the like in the case of oral solid preparations (for example, powders, capsules and tablets).

Because of their ease of administration, tablets and capsules represent an advantageous oral dosage unit form, wherein solid pharmaceutical carriers are employed. If desired, tablets may be sugar-coated or enteric-coated by standard techniques. For parenterals, the carrier will usually comprise sterile water, though other ingredients for solubility or preservative purposes may also be included. Injectable suspensions may also be prepared, wherein appropriate liquid carriers, suspending agents and the like may be employed. The compounds may also be administered in the form of an aerosol.

The present invention also provides a method for reducing ischemic death in a cell population comprising contacting the cell with a prophylactically effective amount of the compound contained in any of the instant pharmaceutical compositions.

As used herein, a "prophylactically effective amount" of the instant pharmaceutical composition, or compound therein, means an amount that reduces the incidence of cell death in a population of cells. The instant pharmaceutical composition will generally contain a per dosage unit (e.g., tablet, capsule, powder, injection, teaspoonful and the like) from about 0.001 to about 100 mg/kg. In one embodiment, the instant pharmaceutical composition contains a per dosage unit of from about 0.01 to about 50 mg/kg of compound, and preferably from about 0.05 to about 20 mg/kg. Methods are known in the art for determining prophylactically effective doses for the instant pharmaceutical composition. The effective dose for administering the pharmaceutical composition to a human, for example, can be determined mathematically from the results of animal studies.

A "cell population" as used herein refers to cells in vitro such as in a culture vessel or in vivo as part of a body fluid or as an intact tissue or organ. The cell population can be homogenous (comprising of one cell type) or heterogenous (comprising a mixed cell type population). Preferred cell populations are heterogenous

cell populations that comprise at least one cell type that has been identified as being protected from ischaemic death in the presence of the compounds of this invention.

In one embodiment of the instant method, the cells making up the cell
5 populations are preferably mammalian cells and more preferably human cells. The cells that make up a cell population that demonstrates reduced ischaemic injury in response to a traumatic event include, but are not limited to, cell populations comprising at least one cell selected from the group consisting of a neuronal cell, a glial cell, a cardiac cell, a lymphocyte, a macrophage and a fibroblast. In the preferred
10 embodiment, the cell is a neuronal cell.

The present invention also provides a method for reducing neuronal cell death in response to a traumatic event comprising contacting the neuronal cell with a prophylactically effective amount of the compound contained in any of the instant
15 pharmaceutical composition prior to, during, or within a suitable time period following the traumatic event.

Both these instant methods can be performed *in vitro*, *ex vivo*, or *in vivo*. As used herein, contacting a cell with an agent "*in vitro*" includes, by way of example,
20 contacting such agent with a cell that is in a single cell culture, a mixed cell culture or a primary cell tissue culture. Contacting a cell with an agent "*ex vivo*" includes, by way of example, contacting such agent with a cell that is part of an organized tissue or organ maintained outside the body of the subject from which it originates. Contacting a cell with an agent "*in vivo*" means contacting such agent with a cell present within a subject.

25 The present invention further provides a method of reducing neuronal cell death in response to a traumatic event in a subject, comprising administering to the subject a prophylactically effective amount of any of the instant pharmaceutical compositions prior to, during, or within a suitable time period following the traumatic event. The
30 term "subject" includes, without limitation, any animal or artificially modified animal. In the preferred embodiment, the subject is a human.

1 The route of administering any of the instant pharmaceutical compositions to a
subject is preferably systemic, including, for example, intravenous (iv), subcutaneous (sc)
and oral administration. In one embodiment, the instant composition is administered
directly to the nervous system. This administration route includes, but is not limited to,
5 the intracerebral, intraventricular, intracerebroventricular, intrathecal, intracisternal,
intrapinal and/or peri-spinal routes of administration, which can employ intracranial
and intravertebral needles, and catheters with or without pump devices. Infusion doses
can range, for example, from about 1.0 to 1.0×10^4 $\mu\text{g/kg/min}$ of instant compound,
over a period ranging from several minutes to several days. For topical administration,
10 the instant compound can be mixed with a pharmaceutical carrier at a concentration of,
for example, about 0.1 to about 10% of drug to vehicle.

15 In the instant method, the neuronal cell death-causing traumatic event includes,
for example, a medical disorder, a physical trauma, a chemical trauma or a biological
trauma.

Examples of neuronal cell death-causing medical disorders include, but are not
limited to, perinatal hypoxic-ischemic injury, cardiac arrest, stroke/ischemic attack,
hypoglycemia-induced neuropathy, cardiac surgery-induced cerebral ischemia, post
20 traumatic stress disorder, stress-induced memory impairment, chronic epilepsy,
multiple sclerosis, Parkinson's disease, diabetic peripheral neuropathy, neuropathic
pain, Bells' palsy, sick sinus syndrome, Alzheimer's disease, Pick's disease, diffuse
Lewy body disease, Cruzeiro's Jacobs and other diseases of protein aggregation,
progressive supranuclear palsy (Steel-Richardson syndrome), multisystem degeneration
25 (Shy-Drager syndrome), amyotrophic lateral sclerosis (ALS), degenerative ataxias,
cortical basal degeneration, ALS-Parkinson's-Dementia complex of Guam, subacute
sclerosing panencephalitis, Huntington's disease, synucleinopathies (including multiple
system atrophy), primary progressive aphasia, striatonigral degeneration, Machado-
Joseph disease, spinocerebellar ataxia type 3, olivopontocerebellar degenerations,
30 Gilles De La Tourette's disease, bulbar and pseudobulbar palsy, spinal and spinobulbar
muscular atrophy (Kennedy's disease), primary lateral sclerosis, familial spastic
paraplegia, Werdnig-Hoffmann disease, Kugelberg-Welander disease, Tay-Sach's
disease, Sandhoff disease, familial spastic disease, neuroleptic malignant syndrome,

Wohlfart-Kugelberg-Welander disease, spastic paraparesis, progressive multifocal leukoencephalopathy, AIDS-related dementia, sick sinus syndrome, post herpetic neuropathy, viral meningitis, bacterial meningitis, prion diseases, and familial dysautonomia (Riley-Day syndrome).

5

Neuronal cell death-causing physical traumas include, for example, focal brain trauma, diffuse brain trauma, spinal cord injury, cerebral infarction, embolic occlusion, thrombotic occlusion, reperfusion, intracranial hemorrhage, whiplash, shaken infant syndrome, and radiation-induced peripheral nerve damage.

10

Neuronal cell death-causing chemical traumas include, for example, exposure to alcohol, chemotherapeutic agents, war gas, lead, cyanoacrylate, polyacrylamide, and toxic inhalants. Finally, neuronal cell death-causing biological traumas include, for example, exposure to HIV, herpes virus, and meningitis-causing bacteria and viruses.

15

In practicing the instant method, the pharmaceutical composition can be administered to the subject prior to, during or subsequent to the traumatic event. As used herein the term "subsequent" refers to any point in time beginning with the traumatic event and continuing until the potential of cell death resulting from the traumatic event has diminished.

20

Finally, the present invention provides an apparatus for administering to a subject any of the instant pharmaceutical compositions comprising a container and the pharmaceutical composition therein, wherein the container has a device for delivering to the subject a prophylactic dose of the pharmaceutical composition. In the preferred embodiment, the device for delivering the pharmaceutical composition is a syringe. Ideally, the instant apparatus is a single-use, predosed auto-injectable device containing the instant composition. Such a device would be useful, for example, in a mobile ambulatory unit or for administration to a person at risk for a neurotoxic event.

25

Mechanical auto-injectable devices are well known in the art and are exemplified, for example, by an EpiPen® device (Meridian Medical Technologies Inc.), which is an auto-injectable device containing epinephrin for individuals subject to anaphalactic shock.

30

This invention will be better understood by reference to the Experimental Details that follow, but those skilled in the art will readily appreciate that these are only illustrative of the invention as described more fully in the claims which follow thereafter.

- 5 Additionally, throughout this application, various publications are cited. The disclosure of these publications is hereby incorporated by reference into this application to describe more fully the state of the art to which this invention pertains.

Experimental Details

10

Example 1

Commercially Available 4-Pyrimidinamines

	<p>1,4-benzenediamine, <i>N</i>¹,<i>N</i>¹-dimethyl-<i>N</i>⁴-[6-[4-(phenylmethoxy)phenyl]-4-pyrimidinyl]- (Cmpd 42)</p>
	<p>1,4-benzenediamine, <i>N</i>¹-(6-[1,1'-biphenyl]-3-yl-4-pyrimidinyl)-<i>N</i>⁴,<i>N</i>⁴-dimethyl- (Cmpd 43)</p>
	<p>1,4-benzenediamine, <i>N</i>¹-[6-[3,5-bis(trifluoromethyl)phenyl]-4-pyrimidinyl]-<i>N</i>⁴,<i>N</i>⁴-dimethyl- (Cmpd 44)</p>
	<p>ethanol, 2-[[4-[(6-[1,1'-biphenyl]-3-yl-4-pyrimidinyl)amino]phenyl]ethylamino]- (Cmpd 46)</p>

	ethanol, 2-[[4-[(6-benzo[<i>b</i>]thien-2-yl-4-pyrimidinyl)amino]phenyl]ethylamino]- (Cmpd 54)
	ethanol, 2-[ethyl[4-[[6-[4-(trifluoromethoxy)phenyl]-4-pyrimidinyl]amino]phenyl]amino]- (Cmpd 51)
	2-{[4-(2',4'-is-benzyloxy-[4,5']bipyrimidinyl-6-ylamino)phenyl]-ethyl-amino}-ethanol (Cmpd 58)

Example 2 Characterization of Differentiated P19 Cells

P19 Cell Differentiation

- 5 P19 cells are a pluripotent embryonal carcinoma line that can be induced to differentiate relatively rapidly into post-mitotic neurons in the presence of high dose retinoic acid (Jones-Villeneuve et al. 1982; Jones-Villeneuve et al. 1983; McBurney and Rogers 1982). They are the murine equivalent of human NT-2N neurons, which are also derived from retinoic acid differentiation of teratocarcinoma precursor cells.
- 10 Differentiated NT-2N neurons, perhaps the better known of the two teratocarcinoma-derived neuronal lines, express a wide variety of neuronal markers, and undergo NMDA receptor-mediated, hypoxia-induced excitotoxic cell death (Pleasure and Lee 1993; Pleasure, Page, and Lee 1992; Rootwelt et al. 1998). Like NT-2Ns, differentiated P19 neurons also express a wide variety of neuronal markers, exhibit NMDA receptor-
- 15 mediated intracellular calcium responses to agonists, and undergo excitotoxicity (Canzoniero et al. 1996; Grobin et al. 1999; Morley et al. 1995; Ray and Gottlieb 1993; Turetsky et al. 1993).

P19 cells were bought from ATCC (Manassas, VA). They were grown on 150 cm² tissue culture flasks in Dulbecco's Modified Eagle Medium (DMEM, Gibco BRL) supplemented with 10% fetal bovine serum, glutamine (2 mM), sodium pyruvate (1 mM), sodium bicarbonate (0.15% w/v), and penicillin/streptomycin (50 units/mL) in an atmosphere of 5% CO₂ at 37°C.

On day 1 of the differentiation protocol, confluent P19 cells were split to 50-70% confluency in growth medium. On day 2 of the protocol, 10 µM all-trans-retinoic acid (ATRA, Sigma) and 10 µM MK-801 were added to the growth medium. 10 µM MK-801 was included at this stage to prevent cell death in differentiating neurons that begin to express NMDA receptors. On day 4, fresh growth medium was placed on the cells, with fresh ATRA and MK-801. On day 5, cells were dissociated from the tissue culture flask by washing 4 times with calcium and magnesium-free phosphate-buffered saline, and adding 4 mL of non-enzymatic cell dissociation solution (Sigma).

Once dissociated, cells were placed in 40 mLs of differentiation medium. Differentiation medium consisted of Neurobasal medium (Gibco BRL) supplemented with 1% N-2 supplement (Gibco BRL), 0.1 % trace elements B (Mediatech), 1 mM cadmium sulfate (Sigma), 2 mM glutamine, sodium pyruvate (1 mM), sodium bicarbonate (0.15% w/v), and 1% antibiotic/antimycotic (Gibco BRL). 10 µM cytosine-D-arabino-furanoside was added to the differentiation medium to prevent growth of undifferentiated cells. No MK-801 was present from this point onward. Cells were triturated 20 times, then were split 1:4 into 96 well plates, or split 1:3 into 100 mm tissue culture dishes. Four days after replating, the cells were optimal for compound addition, and were assayed 24 hours later.

25

RT-PCR

Total RNA was isolated from 100 mm tissue culture dishes of differentiated P19 neurons or undifferentiated P19 cells using the QIAGEN RNeasy Mini kit according to manufacturer's protocols. RT-PCR amplification of murine NMDA receptor subunits was obtained from 250 ng total RNA template isolated from undifferentiated P19 cells, cells at 4 days after retinoic acid (ATRA) induction, and cells at 9 days after ATRA induction. One-step RT-PCR reactions were set up using the LightCyclerTM-RNA Amplification kit SYBR Green I kit (Boehringer Mannheim), according to

manufacturer's protocols. Real time RT-PCR reactions were carried out in LightCycler™ glass capillaries using the LightCycler™ instrument and 250 ng template RNA (Boehringer Mannheim). The reverse transcriptase reaction was carried out for 10 min at 55°C. PCR was carried out for 30 cycles: annealing temperature was 50°C, extension temperature was 72°C, and melting temperature was 80°C. Reactions were compared to an H₂O-negative control for each primer set. 5 µL of reaction product were removed, and run on 1x TBE agarose gels. The primer sets for the various mouse NMDA receptor subunits used include zeta 1 and epsilons 1-4.

RNA samples from 4-day and 9-day post retinoic acid treatment, undifferentiated samples and control samples were separated by electrophoresis and probed with zeta1, epsilon 1 and epsilon 2 internal primers

RT-PCR of NMDA receptor subunits from total RNA samples revealed that retinoic acid induction of differentiation also induces mRNA expression of zeta1, epsilon1, and epsilon2 mRNAs. Data was summarized using 3 separate experiments.

Western Blots

Media was aspirated from cells plated onto 100 mm tissue culture dishes. Cells were harvested in RIPA lysis buffer (100mM Tris HCL pH 7.5, 150 mM NaCl, 1 mM EDTA, 1% Triton X-100, 10% sodium deoxycholate, 0.1% sodium dodecyl sulfate). Each sample was sonicated for 20 seconds, Laemmli sample buffer (BioRad) was added to a final 1x concentration, and samples were incubated for 10 minutes at 95°C. Samples to be probed with NMDA receptor antibodies (polyclonals against rat NR1, NR2A, and NR2B obtained from Chemicon) were electrophoresed on 6% tris-glycine pre-cast gels (NOVEX). Samples to be probed with p42/44 MAP kinase antibodies (New England BioLabs) were electrophoresed on 12% tris-glycine pre-cast gels (NOVEX). Electrophoresis was carried out in a NOVEX apparatus for 1.5 hours at 200 volts. Proteins were transferred to polyvinylidene difluoride membrane (PVDF, NOVEX) using a BioRad wet transfer device for 1 hour at 100 volts. Prior to transfer, PVDF membranes were dipped in 100% methanol for 1 minute, then soaked in transfer buffer for 5 minutes. After transfer, membranes were removed and were slowly shaken in blocking solution (5% milk, 0.05% tween-20 in phosphate buffered saline) at 4°C overnight. Membranes were then washed once with PBS-tween, and primary antibodies 1:1000 in PBS-tween with 5 % milk were incubated for 1 hour at room

temperature. Membranes were washed 4x for 15 minutes at room temperature. Secondary antibodies coupled to horseradish peroxidase were incubated for about 45 minutes at room temperature in PBS-tween with 5 % milk. Membranes were then washed 4x for 15 minutes at room temperature. Blots were developed using ECL plus (Amersham), and exposed to film.

Western blot analysis was performed for NMDA receptor subunit protein in P19 cell lysates harvested following 4-days or 9-days of retinoic acid exposure.

Appropriately sized bands (Zeta1 = ~ 120 kDa, Epsilon1 and Epsilon 2 = ~ 180 kDa) were detectable from terminally differentiated P19 neuron lysates, but not from undifferentiated cell lysates. The data was representative of 3 separate experiments with similar results.

Western blot analysis revealed that terminally differentiated P19 neurons express detectable levels of zeta1, epsilon1, and epsilon 2 proteins. Epsilon3 and epsilon4 mRNAs or proteins were not detectable at any time in these cells.

These data demonstrate that such methods of differentiating P19 cells into neurons successfully result in the functional expression of NMDA receptors at the levels of mRNA, protein, MK-801 sensitive agonist-induced intracellular calcium responses, and MK-801 sensitive glutamate toxicity. These data are in very good agreement with the literature. Interestingly, however, in addition to zeta1 and epsilon2 expression, reliable expression of the epsilon1 subunit of the NMDA receptor was also achieved, which expression has not yet been achieved with other reported methods of P19 cell differentiation (Ray and Gottlieb 1993). The presence of all three subunits more closely resembles expression patterns observed in adult rodent forebrain regions, including cortex and hippocampus (Ishii et al. 1993; Laurie et al. 1995; Monyer et al. 1994; Monyer et al. 1992; Standaert et al. 1994).

Example 3

Differentiated P19 Excitotoxicity Assay

Cells were loaded with 5 μ M Fura-2-AM (Molecular Probes) for 1 hr at 37°C. They were washed once with Hank's balanced salt solution (HBSS, Gibco BRL), and assayed in HBSS buffer. Cells were placed onto the stage of a modified ATTOFLUOR™ Imager (Atto Instruments, Rockville Pike, MD). High speed, dual excitation of fura-2 was carried out using a RATIOARC™ High-Speed Excitor (Atto

Instruments). Mercury lamp light was passed through 334 nm or 380 nm bandpass filters (10 nm band width), and then passed through a 20x objective (Zeiss, Plan-Apochromat, NA=0.75) at a rate of 2.5 Hz. Emitted light was transmitted through a 400 nm dichroic mirror, and collected to an ATTOFLUOR™ intensified CCD camera.

- 5 Ratio-images were acquired, and the average intensity of the images when excited at 334nm and 380nm was analyzed using ATTOFLUOR RATIOVISION™ software (Atto Instruments, Rockville, MD).

- Changes of the Fura-2 330nm/380nm intensity ratio were plotted when 9 days post-ATRA P19 neurons were treated with 3 mM glutamate, 1 mM glycine in the
10 presence or absence of 100 μM MK-801. MK-801 was administered 24 hours prior to assay. Traces are the average ± standard error from three separate experiments for each condition. Terminally differentiated P19 neurons expressed NMDA receptor subunits that form functional NMDA receptors, as illustrated by using fura-2 imaging to detect increases in intracellular calcium levels upon addition of NMDA receptor agonists
15 (Figure 1A). The selective NMDA receptor channel blocker, MK-801, significantly inhibited this response (Figure 1A). In addition P19 neurons expressed specific binding sites for the NMDA receptor. MK-801 inhibition of [³H]-MK-801 binding was assayed in P19 membranes. MK-801 concentrations are expressed as 10^{-x} Molar. Data points represent the mean ± standard error from eight experiments. % control = ((CPM –
20 CPM_{bottom})/(CPM_{top}-CPM_{bottom})) X 100. (Figure 1B). MK-801 inhibition was concentration-dependent, and 100% inhibition was achieved.

- Control P19 neuron cell bodies and processes stain brightly with the live cell cytoplasmic dye carboxyfluorescein diacetate (CFDA). P19 neurons at 9 days post ATRA induction were labeled with CFDA, and then imaged in confocal mode using an
25 Attofluor Imager. Control cells were treated with vehicle for 24 hours, glutamate cells received 3 mM glutamate in the presence of 1 mM glycine for 24 hours, and glutamate + U0126 cells received 10 μM U0126 concurrent with 3 mM glutamate and 1 mM glycine for 24 hours. Images were taken from control alive, glutamate treated, dead and U0126-protected cells stained with fluorescein diacetate in 3 separate experiments. P19
30 neuron cell bodies characteristically clumped together into tight aggregates when plated onto plain tissue culture plastic. Networks of extensive processes connected clusters of neuronal cell bodies. P19 neurons treated with toxic concentrations of glutamate and glycine for 24 hours exhibited fluorescence staining in isolated cell bodies, processes

were undetectable, and extensive cellular debris was evident. Relative levels of cell death were measured rapidly and quantitatively on a plate reader using the live cell fluorescent dye alamar blue (Figures 2B).

Alamar Blue fluorescence, an indicator of cell viability, was used to determine cell viability after an NMDA-induced cytotoxic insult. Counts from a single 96 well plate where 32 wells received vehicle control, 32 wells received 3 mM glutamate and 1 mM glycine for 24 hours, and 32 wells received 5 μ M A23187 for 24 hours are shown in Figure 2A. Glutamate and A23187 conditions were significantly different from control as determined by one-way ANOVA with Tukey post-hoc analysis carried out using GRAPHPAD™ software. These data indicate a typical 60% reduction in Alamar blue fluorescence when cells were treated with glutamate and glycine. However, since raw fluorescence counts vary from experiment to experiment, Figures 2A, 2B, and 2C are expressed as a percent of control.

Glutamate toxicity dose response in the presence of a constant 1 mM glycine concentration was measured in the differentiated P19 neurons. The curve generated through the data points is the average of 6 separate dose response curves. Data points are represented as the percent of control cells \pm standard error. % control = $(([\text{Glutamate}]_{\text{exp}} - [\text{Glutamate}]_{\text{max}}) / (\text{Control}_{\text{vehicle}} - [\text{Glutamate}]_{\text{max}})) \times 100$. Glutamate toxicity EC50 was calculated to be 8.1 μ M [lower 95% confidence interval = 3.5 μ M; upper 95% confidence interval = 19 μ M]. These data demonstrate that 24 hours of glutamate treatment killed P19 neurons dose-dependently in the presence of a constant dose of glycine (Figures 2A,2B). Glycine alone did not affect P19 neuron viability.

The NMDA receptor blocker, MK-801, dose-dependently protected against glutamate toxicity in P19 neurons (Figure 2C). MK-801 dose-dependent inhibition of 3 mM glutamate and 1 mM glycine-induced P19 neuron death. % Neuroprotection = $((\text{Inhibitor in the presence of Glutamate}_{\text{max}} - [\text{Glutamate}]_{\text{max}}) / (\text{Control}_{\text{vehicle}} - [\text{Glutamate}]_{\text{max}})) \times 100$. Data points are the average \pm standard error of three separate experiments. Maximal MK-801 protection achieved was close to control levels.

These data demonstrate that glutamate toxicity in P19 neurons requires NMDA receptor activation, since the toxicity is completely blocked in the presence of the specific NMDA receptor antagonist MK-801. However, the data do not exclude the possibility that AMPA or kainate receptors may also be activated by glutamate and contribute to the excitotoxicity. This possibility would be consistent with data from

primary neuronal culture, which reports that intracellular calcium responses to glutamate agonists involve multiple components (Courtney, Lambert, and Nicholls 1990). Such components include AMPA/kainate receptor activation, membrane depolarization, voltage-gated calcium channel activation, relief of NMDA receptor magnesium block, and NMDA receptor activation. However, even with such a high level of complexity, in many primary neuronal models, glutamate excitotoxicity signals through the NMDA receptor and requires its activation to result in neuronal death (Tymianski et al. 1993), as is the case for P19 neuron model system.

These cells were used to measure the effects of various known kinase inhibitors (Compound Identification (ID) column in Table I) upon cytotoxicity-induced by NMDA. First, P19 cells were differentiated as described in Example 2. Then cells were exposed to 3 mM of glutamate in the presence of 1 mM glycine.

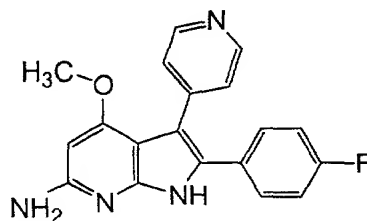
Cell viability was determined. Compounds that prevented excitotoxicity were determined by measuring the percentage of viable cells compared to differentiated P19 cells that were not presented with a toxic insult (Table I).

Cell viability was measured using two methods. The first method was a confocal, single-cell fluorescence imaging-based method using the live cell dye carboxy-fluorescein diacetate (CFDA). CFDA labels the cell bodies and processes of living cells. Therefore, live cells exhibit extensive CFDA labeling, whereas dead cells exhibit much less CFDA staining. CFDA fluorescence was measured using a modified Attofluor Imager device (Atto Instruments, Rockville Pike, MD). Cells were labeled with 1 μ M CFDA for 15 min in media, then placed onto the stage of the Attofluor microscope. The dye was excited by light from a mercury lamp source passed through a 488 nm bandpass filter of 10 nm band width, passed through a CARV real-time confocal spinning disk module (Atto Instruments, Rockville, MD), and then passed through a 40x oil immersion objective (Zeiss Fluor, NA=1.3). Emitted light was transmitted through a 495 nm dichroic mirror, collected to an Attofluor intensified CCD camera, and images were visualized using Attofluor RatioVision software (Atto Instruments, Rockville, MD).

The second method for measuring cell viability was a plate reader method. Cells plated into black 96 well plates (Packard viewplates) were loaded with 5 % Alamar Blue dye (Biosource International). Alamar Blue is a dye that takes advantage of mitochondrial reductases to convert non-fluorescent resazurin to fluorescent

resorufin (excitation 535 nm, emission 580 nm). Baseline fluorescence counts were read at room temperature in a Wallac plate reader immediately after addition of Alamar blue. Fluorescence counts of cell viability were taken the same way after 1 hour incubation at 37°C. Fluorescence was expressed as a percent of control, untreated cells after subtraction of background fluorescence. Live/dead cells were confirmed visually with a light microscope.

As used in Table I below, Compound A shall mean the compound have the formula



10

Table I
Comparison of Kinase Inhibitor Activity to Neuroprotective Activity

Compound ID	Enzyme target	Activity	Potency	IC50 for Neuroprotection [lower-upper 95% C.I.]	Maximal Efficacy for Neuroprotection
Compound A	p38 kinase	Inhibitor	IC50~10 nM	9.7 μ M [5.8-16.3]	>80%
U0126	MEK1/2	Inhibitor	IC50~0.5 μ M	1.1 μ M [0.74-1.7]	>80%
SB202474	p38 kinase	Inactive	Nonapplicable	>10 μ M	>50%
SB203580	p38 kinase	Inhibitor	IC50~600 nM	Ineffective	<10%
Lithium	IP3 turnover	Inhibitor	Ki~0.5 μ M	Ineffective	<10%
KN62	CAMKII	Inhibitor	Ki~900 nM	Ineffective	<10%
Calphostin C	PKC PKA PKG p60 ^{C-src}	Inhibitor Inhibitor Inhibitor Inhibitor	IC50~50 nM IC50>50 μ M IC50>25 μ M IC50>50 μ M	>1 μ M	~50%

Lavendustin A	EGF receptor p60 ^{c-src}	Inhibitor Inhibitor	IC50~11 nM IC50~500 nM	>10 μ M	<25%
H-89	PKA CAMKII Casein kinase I PKC	Inhibitor Inhibitor Inhibitor Inhibitor	Ki~48 nM Ki~30 μ M Ki~38 μ M Ki~31.7 μ M	>10 μ M	<25%

Kinase inhibition activities and potencies were derived from the literature (Chijiwa et al. 1990; Favata et al. 1998; Henry et al. 1998; Inhorn and Majerus 1987; Kobayashi et al. 1989; Lee et al. 1994; Onoda et al. 1989; Tokumitsu et al. 1990).

- 5 IC50s for neuroprotection are the mean of three separate curves with upper and lower 95% confidence intervals (C.I.) shown. Curves were fit, and confidence intervals were determined using GraphPad Prism software.

Example 4

10 Evaluation of a MEK1/2 Inhibitor in the Differentiated P19 Assay

U0126 (bis[amino[(2-aminophenyl)thio]methylene] Butanedinitrile) is reported to be highly selective for MEK1/2 (Favata et al. 1998), a result that was confirmed here. The only other kinase found that U0126 inhibits is PKC- γ , but the IC50 for inhibition of this enzyme was 60-fold higher than its published IC50 against wildtype MEK1/2

- 15 (Tables II and III below).

The general procedure used to assay for kinase activity was as follows: a kinase reaction mix was prepared in 50 mM Tris-HCl pH=8, 10 mM MgCl₂, 0.1 mM Na₃VO₄, 1 mM DTT, 10 μ M ATP, 0.25-1 μ M biotinylated peptide substrate, 0.2-0.8 μ Curies per well ³³P- γ -ATP [2000-3000 Ci/mmol]. Assay conditions varied slightly for each

- 20 protein kinase, for example, insulin receptor kinase requires 10 mM MnCl₂ for activity and calmodulin-dependent protein kinase requires calmodulin and 10 mM CaCl₂.

Reaction mix was dispensed into the wells of a streptavidin-coated Flashplate and 1 μ L drug stock in 100% DMSO was added to a 100 μ L reaction volume resulting in a final concentration of 1% DMSO in the reaction. Enzyme was diluted in 50 mM Tris-HCl
25 pH=8.0, 0.1 % BSA and added to each well. The reaction was incubated for one hour at 30°C in the presence of compound. After one hour the reaction mix was aspirated from the plate and the plate washed with PBS containing 100 mM EDTA. The plate was read on a scintillation counter to determine ³³P- γ -ATP incorporated into the

immobilized peptide. Test compounds were assayed in duplicate at 8 concentrations ranging from 100 μ M to 10 pM in one order of magnitude steps. A maximum and minimum signal for the assay was determined on each plate. The IC₅₀ was calculated from the dose response curve of the percent inhibition of the maximum signal in the assay according to the formula [max signal – background/test compound signal-background (100) = % inhibition] by graphing the percent inhibition against the log concentration of test compound. Known inhibitor compounds appropriate for the kinase being assayed were also included on each plate. Results are provided in Figure 3.

Definition and Source of Kinase Enzymes

VEGF-R (vascular endothelial growth factor receptor-2) is a fusion protein containing a polyhistidine tag at the N-terminus followed by amino acids 786-1343 of the rat VEGF-R2 kinase domain. CDK1 (cyclin dependent kinase 1) is isolated from insect cells expressing both the human CDK1 catalytic subunit and its positive regulatory subunit cyclin B. Insulin Receptor Kinase consists of residues 941-1313 of the cytoplasmic domain of the beta-subunit of the human insulin receptor. Protein Kinase A is the catalytic subunit of cAMP-dependent protein kinase-A purified from bovine heart. PKC (protein kinase-C) is the gamma or beta isoform of the human protein produced in insect cells. Casein Kinase 1 is a truncation at amino acid 318 of the C-terminal portion of the rat CK1 delta isoform produced in *E. coli*. Casein Kinase 2 includes the alpha and beta subunits of the human CK2 protein produced in *E. coli*. Calmodulin Kinase (calmodulin-dependent protein kinase 2) is a truncated version of the alpha subunit of the rat protein produced in insect cells. Glycogen Synthase Kinase-3 is the beta isoform of the rabbit enzyme produced in *E. coli*. MAP Kinase is the rat ERK-2 isoform containing a polyhistidine tag at the N-terminus produced in *E. coli* and activated by phosphorylation with MEK1 prior to purification. EGFR (epidermal growth factor receptor) is purified from human A431 cell membranes. The chart below shows selected kinases and their control inhibitors.

As used in Table III below, Compound A (Cmpd A) shall mean the compound have the formula

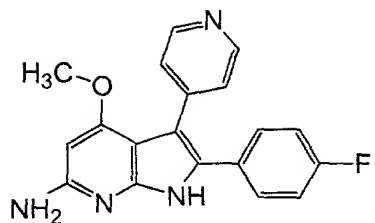


TABLE II

Selected Kinases and Their Control Inhibitors

<u>Kinase</u>	<u>Control Inhibitor</u>
CDK1	Butyrolactone
EGFR	AG-1478
Protein Kinase A	H89
PKC	Staurosporine
Casein Kinase 1	H89
Casein Kinase 2	
Calmodulin Kinase	Staurosporine
Insulin Kinase	Staurosporine

5

Table III

Kinase Selectivity of Compound A and U0126

Compound ID	CDK1 (μM)	EGF-R (μM)	PK A (μM)	PKC-γ (μM)
Cmpd A	>100	>100	>100	8.35
U0126	>100	>100	>100	29.5
Compound ID	Casein Kinase 1 (μM)	Casein Kinase 2 (μM)	Calmodulin Kinase (μM)	Insulin Receptor Kinase (μM)
Cmpd A	0.116	>100	>100	>100
U0126	>100	>100	>100	ND

IC50 values for kinase inhibition are the mean of at least two separate curves, and were determined using GraphPad curve fitting software.

1
To determine whether U0126 inhibits the MEK1/2 enzymes in P19 neurons, its ability to block glutamate-induced phosphorylation of the MEK1/2 substrate p42 MAPK (ERK2) was tested. Western blot were first probed using ATRA P19 neuron lysates 9 days post treatment with an antibody specific for the phosphorylated form of p42/44 (ERK1/2) and then stripped and reprobed with antibody that recognized total p42/44 (ERK 1/2). The data demonstrate that the concentrations of glutamate and glycine that were used to induce toxicity in P19 neurons also induced a rapid, reproducible increase in p42 MAPK phosphorylation in these cells. In the presence of U0126, phospho-p42 MAPK was reduced, although no change in the amount of total p42 MAPK was evident. In another Western blot experiment, ATRA P19 neuron lysates were probed 9 days post treatment with an antibody specific for the phosphorylated form of p42/44 (ERK 1/2). The same blot was stripped and reprobed with an antibody that recognized total p42/44 (ERK 1/2). Glutamate-induced elevation of p42 MAPK phosphorylation was sustained, since it was still clearly increased at 24 h versus controls. These blots are representative of 3 separate experiments with similar results. U0126 blocked the increased levels of phosphorylation at this time point as well. No change in total p42 MAPK was evident.

To ensure that U0126 does not block the NMDA receptor directly, P19 neuron intracellular calcium responses to glutamate and glycine were tested in the presence of 10 μ M U0126. Fura-2 imaging traces 9 days post ATRA P19 neurons were treated with 3 mM glutamate, 1 mM glycine in the presence of 10 μ M U0126 for 24 hours. U0126 was administered concurrently with glutamate and glycine. Traces are the average \pm standard error from four separate experiments for each condition.

The data demonstrated that U0126 did not block this intracellular calcium response. (Figure 4A). It was also demonstrated that U0126 did not inhibit [3H]-MK-801 binding in P19 neurons. No significant inhibition was observed at any concentration of U0126. Data points represent the mean \pm standard error from eight experiments. Percent control is defined as described in Figure 1B (Figure 4B). Together, these data further demonstrate that U0126 acts on a signaling pathway downstream of NMDA receptor activation.

The p42/44 MAPK inhibitor, U0126, exhibits delayed neuroprotection

Time-course of efficacy is an extremely relevant parameter for a potential neuroprotective therapeutic agent, since the therapeutic would need to be administered hours to days after an ischemic event and still retain efficacy. The next set of experiments examined whether the MEK1/2 inhibitor, U0126, retains neuroprotective efficacy when added at various time points after glutamate challenge. Assays were performed essentially as described, although the time of administration of the U0126 was delayed relative to the initial excitotoxicity. The data demonstrate that U0126 was maximally neuroprotective up to six hours after glutamate challenge (Figure 5A). However a p38 inhibitor lost efficacy as soon as 15 minutes after glutamate challenge (Figure 5B). U0126 was maximally neuroprotective even when added several hours after the onset of glutamate challenge. This may be because glutamate mediates a sustained increase in p42 MAPK phosphorylation in P19 neurons, detectable even at 24 hours post glutamate addition. U0126 inhibition of the upstream activating enzyme, MEK, several hours after glutamate challenge may favor phosphatase dephosphorylation of p42 MAPK, and restabilize the p42/44 MAPK signaling pathway within enough time to prevent cell death.

Thus, activation of the p42/44 MAP kinase pathway is necessary for glutamate-induced toxicity in differentiated P19 neurons. Glutamate-induced cell death occurs within 24 hours, is dose-dependent, and is NMDA receptor-mediated. Glutamate induces phosphorylation of p42 MAP kinase, which is blocked by U0126, an inhibitor of its upstream kinase, MEK. U0126 also blocks glutamate toxicity in a dose-dependent manner. It is effective when administered before, or even several hours after the onset of glutamate challenge.

A compound that is able to exert delayed neuroprotection even when added after an ischemic event is an especially sought after property of a potential stroke therapeutic. Many compounds with diverse mechanisms are reported to exhibit post-treatment delayed neuroprotection. Among these are glutamate receptor antagonists (Li et al. 1999b; Takahashi et al. 1998; Turski et al. 1998), antioxidants (Callaway et al. 1999; Pazos et al. 1999; Sakakibara et al. 2000), anticonvulsants (Schwartz-Bloom et al. 1998; Wasterlain et al. 1996; Yang et al. 1998), protease inhibitors (Cheng et al. 1998), kinase inhibitors (Tatlisumak et al. 1998), and magnesium (Heath and Vink 1999). However, this is the first demonstration in a cell culture model of NMDA receptor-mediated excitotoxicity wherein a specific inhibitor of the p42/44 MAP kinase

pathway exhibits delayed neuroprotection, and wherein the time window of efficacy extended well after the onset of toxic challenge.

U0126 Neuroprotection is Selective for Glutamate-Induced Toxicity.

5 To determine whether U0126 is protective against a variety of nonspecific toxic insults, or whether the efficacy of this compound is selective for glutamate-induced toxicity, its effects were tested against a variety of other inducers of P19 neuron death.

Figure 6A shows P19 neuron treatment with various concentrations of A23187 for 24 hours in the presence or absence of 10 μ M U0126. Cells were then assayed for
10 Alamar blue fluorescence. The curve generated through the data points is the average of 3 separate dose response curves. Data points are represented as percent of control cells \pm standard error. The EC50 for A23187 toxicity in the absence of U0126 was calculated to be 520 nM [340 nM – 784 nM]. The EC50 for A23187 toxicity in the presence of 10 μ M U0126 was calculated to be 833 nM [440 nM – 1.6 μ M].

15 Figure 6B shows that 1 μ M staurosporine-induced P19 neuron toxicity could not be protected by 10 μ M U0126, as measured by Alamar blue fluorescence at 24 hours after addition. Cells that received vehicle rather than staurosporine exhibited control levels of Alamar blue fluorescence. However no concentration of U0126 brought fluorescence back to control levels in staurosporine-treated cells.

20 Figure 6C demonstrates Alamar blue fluorescence assayed on P19 neurons treated with vehicle or with 10 μ M U0126 in the absence of any inducers of toxicity. U0126 alone did not affect these control levels of fluorescence. The data demonstrate that U0126 was not protective against staurosporine or A23187-induced death (Figures 6A,6B). Additionally, U0126 did not affect the basal viability of P19 neurons (Figure
25 6C).

Example 5

Drug Screening Using Differentiated P19 Cell Assay

Commercially available chemical libraries (BioFocus PLC, UK) were screened
30 using the methods described herein. The stock concentration of the compounds was about 400 μ M in DMSO. The concentration of compounds used in the primary screen was 1 μ M. A positive compound was assigned as one that demonstrated 70% or greater

neuroprotection. Dose-response testing was carried out in 96 well plates where column 1 was vehicle control, column 2 received 3 mM glutamate and 1 mM glycine, and column 3 received 3 mM glutamate, 1 mM glycine, and 10 μ M U0126. Columns 4-11 received compounds at the following final concentrations (μ M): 3, 1.2, 0.48, 0.192, 0.077, 0.031, 0.012 and 0.005. Each row contained a different compound for confirmation. Only rows B-G received compounds, and rows A and H remained untreated. Data are expressed as % neuroprotection = ((compound-glutamate average)/(U0126-glutamate average) X 100).

Compounds of two genres, 4-pyrimidinamines and 2-pyridinamines, were found to display neuroprotective properties as data here show. Only the 4-pyrimidinamines are the subject of this invention, although limited data for 2-pyridinamines are presented as well. The results of this biological testing are summarized in the following tables. "% Inh" indicates the percentage of control cells surviving after 24 hours, and represents the neuroprotective effect of the compounds screened at 1 micromolar concentration. IC₅₀ relate to data from dose response experiments. IC₅₀ values listed as >1 indicate no observed maximum within the highest dose tested (3 μ M), yet indicate biological activity. ND refers to compounds not tested in dose-response experiments.

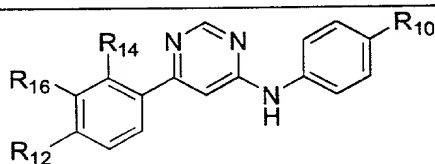
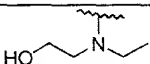
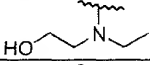
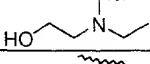
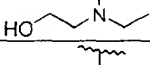
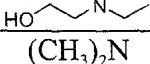
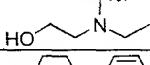
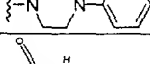

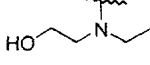
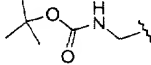
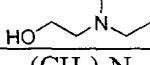


Table IV
N,6-diphenyl-4-pyrimidinamine derivatives

Cmpd	R ₁₀	R ₁₂	R ₁₆	R ₁₄	IC ₅₀ (μ M)	% Inh
41	(CH ₃) ₂ N	fused to form naphthyl		H	0.54	72
42	(CH ₃) ₂ N	O(CH ₃)Ph	H	H	0.2	80
43	(CH ₃) ₂ N	H	Ph	H	0.22	88
44	(CH ₃) ₂ N	H	3,5(CF ₃) ₂	H	0.26	89
45		fused to form naphthyl		H	0.57	93
46		H	Ph	H	0.07	87
47		Ph	H	H	0.49	94
48		H	3,5(CF ₃) ₂	H	0.48	124

49		H	NO ₂	H	0.55	84
50		SCH ₃	H	H	0.41	132
51		OCF ₃	H	H	0.23	144
52		fused to form naphthyl		H	0.57	106
56		H	H	PhO	0.57	77
62	(CH ₃) ₂ N	CN	H	H	>1	175
63	(CH ₃) ₂ N	H	H	PhO	>1	115
64		CN	H	H	>1	106
65		OH	H	H	>1	80
66		fused to form naphthyl		H	ND	100
67	(CH ₃) ₂ N	H	H	PhCH ₂ O	ND	91
147			H	H	1.09	92
148		H	(CH ₃) ₂ N	H	0.47	101
149	(CH ₃) ₂ N	(CH ₃) ₂ N	H	H	0.33	93

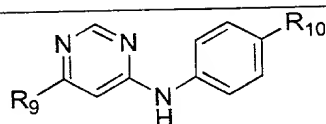


Table V
N-phenyl-4-pyrimidinamine derivatives

Cmpd	R ₉	R ₁₀	IC ₅₀ (μM)	% Inh
53	2,7a-dihydro-2-benzofuranyl		0.54	85.8
54	2,7a-dihydrobenzo-[b]thien-2-yl		0.24	166
55	3-thienyl		0.86	81.8
59	2,7a-dihydro-2-benzofuranyl	(CH ₃) ₂ N	0.48	77
60	2,7a-dihydrobenzo-[b]thien-2-yl	(CH ₃) ₂ N	ND	95
61	1-naphthyl	(CH ₃) ₂ N	>1	131
150	(3-thienyl)	CH ₃ CN	>1	95

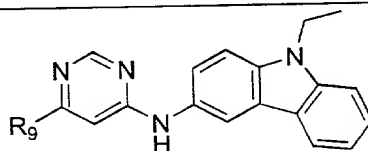


Table VI
9-ethyl-N-(4-pyrimidinyl)-9H-carbazol-2-amine derivatives

Cmpd	R ₉	IC ₅₀ (μM)	% Inh
151	3,4-(CH ₃ O) ₂ Ph	>1	101
152	3,4,5-(CH ₃ O) ₃ Ph	>1	80
153		ND	72
154		0.55	102

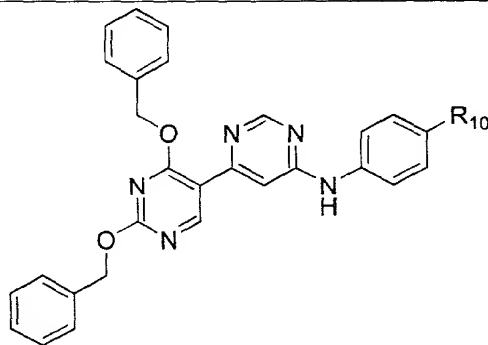


Table VII

6-(5-(2,4 diphenoxy)-pyrimidine)N-phenyl-4-pyrimidinamine derivatives

Cmpd	R ₁₀	IC ₅₀ (μM)	% Inh
57		0.56	79
58		0.39	94

Example 62-Pyridineamine and 4-Pyrimidineamine DerivativesDo Not Inhibit MEK Activity in P19 Neurons.

- 5 The commercially available 2-pyridineamine and 4-pyrimidineamine compounds tested here did not inhibit MEK1/2 kinase activity in P19 neurons since they did not inhibit glutamate-induced p44/42 MAP kinase phosphorylation in these cells. However U0126 did inhibit this activity as expected (Figure 8). MEK activity in P19 neurons was induced by addition of 3 mM glutamate and 1 mM glycine, and measured by
- 10 assaying for phosphorylation of the MEK substrate, p44/42 MAP kinase. Cells were treated with the compounds described herein or with U0126 in the presence or absence of glutamate/glycine, and harvested 5 minutes after treatment, for subsequent Western blot analysis. The data demonstrate that U0126 effectively inhibited phosphorylation of MEK substrate as expected, but that the 2-pyridineamine and 4-pyrimidineamine
- 15 compounds did not. Therefore, the 2-pyridineamine and 4-pyrimidineamines are not MEK inhibitors.

The 2-pyridineamine and 4-pyrimidineamines were maximally neuroprotective at least two hours after the onset of excitotoxicity. Compounds were administered at a concentration of 1 μM either 15 minutes before or 2 hours after glutamate/glycine

addition. U0126 was tested as a positive control. Similar to U0126, the 2-pyridinamine and 4-pyrimidinamine compounds retained maximal neuroprotective efficacy at both time points despite being active at a different target.

5

Example 7

In Vivo Model of Neuroprotection:

Middle Cerebral Artery Occlusion Protocol

Spontaneous hypertensive (SHR) male rats, approximately 90-100 days old (~250-300g), are weighed and then anesthetized with ketamine (100mg/ml)/ xylazine (20mg/ml) cocktail (1.2ml/kg; i.p.) followed by subcutaneous administration of a long-acting antibiotic (e.g., combiotic). The level of anesthetic is assessed by corneal reflex (air puff to eye) and leg jerk in response to tail or foot pinch. Once the rat is anesthetized, it is placed on a small animal surgical board and restrained during the surgical procedure. The rat's body temperature is monitored with a rectal probe and maintained at 37°C with a homeostatic heating pad. Areas of incision are shaved and swabbed with betadine. The surgical area is aseptic. All surgical instruments are sterilized in an autoclave and/or in a glass bead dry instrument sterilizer, then rinsed with sterile saline or alcohol before use.

(1) Femoral Artery Catheter. An indwelling catheter is placed in the femoral artery for periodic blood sampling and measurement of arterial blood pressure. An incision is made over the area of the femoral artery. Tissue is blunt dissected to isolate the artery. The distal end of the artery is ligated with sterile suture and a loose ligature is placed around the proximal end for securing the catheter in place. A small incision is made in the artery for insertion of the catheter. The bevel-tipped end of PE50 tubing is inserted 5mm into the artery and then secured in place by sterile suture. The PE tubing is attached to a 1cc syringe filled with heparinized saline that is used minimally to keep the artery patent. Arterial blood is sampled three times: 10 minutes before ischemia, 2h after the onset of ischemia and 15 minutes post-reperfusion. All blood samples are taken in 100-300µl volumes to determine pH, PaO₂, PaCO₂, hematocrit and glucose. The maximum amount of blood withdrawn throughout the experiment does not exceed 1ml per animal. When blood sampling is not occurring, a blood pressure transducer is attached to the catheter to measure mean arterial pressure. At the end of the surgical procedure, the catheter is removed, the artery tied off and the incision area sutured shut.

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(2) Tandem CCA-MCA Occlusion Model of Focal Cerebral Ischemia. Male spontaneously hypertensive Wistar rats (SHRs) are prepared for reversible focal cerebral ischemia by unilateral occlusion of both the common carotid artery (CCA) and the middle cerebral artery (MCA), using a modification of the technique described by Brint and co-workers (J. Cereb Blood Flow Metab 8:474-485, 1988). The left CCA is isolated through an incision in the ventral surface of the neck. For isolation of the ipsilateral MCA, a second incision is made between the lateral canthus of the left eye and the corresponding external auditory canal to bare the underlying skull. The MCA is exposed through a 5mm burrhole drilled 2-3mm rostral to the fusion of the zygomatic arch and the squamosal bone under direct visualization with a Zeiss operating microscope. The dura is opened with a sterile 26g needle and a platinum wire (0.1mm diameter) is inserted beneath the MCA just superior to the inferior cortical vein. The MCA is temporarily occluded by elevation and compression of the vessel across the platinum wire, as described by Aronowski and colleagues (Stroke, 25:2235-2240, 1994). Concurrently, the CCA is occluded with an aneurysm clip. The duration of occlusion of the CCA and the MCA is 2h. At the end of this period, the wire and the clip are carefully removed to allow reperfusion of the vessels and the incision area is sutured shut. The rat is placed in an isolation cage to recover before returning to his home cage. The rat is closely monitored for 2-4h post surgery to ensure uneventful recovery from the anesthesia and surgical procedure. Following recovery from anesthesia, the rat is housed according to the established protocol as per LAM guidelines until required for the experimental analysis.

(3) Test compounds are administered by any suitable route: intravenous, subcutaneous, or intraperitoneal. Dose and time of compound administration is based on *in vitro* assay results or literature references.

(4) Two outcome measures are used to assess compound efficacy: (a) behavioral performance on several CNS paradigms such as the Morris Water Maze, spontaneous motor activity, radial arm maze, and CNS general behavior profile; and (b) histological examination of the size of the cerebral cortical infarct. Twenty-four hours post-ischemia, the rats are tested in a behavioral paradigm and subsequently euthanized for brain histology. Rats are deeply anesthetized with an intraperitoneal injection of sodium pentobarbital (100 mg/kg, i.p). Depth of anesthesia is checked by lack of corneal reflex and tail pinch. Rats are euthanized by transcardial perfusion with

approximately 50 ml heparinized physiological saline. After perfusion, the brain is removed, blocked and sectioned into 1mm slabs. Each slab is placed in TTC solution, a cell viability dye, for 15 min. The stained slabs are visualized with a Nikon SMZ-U dissecting microscope and image analysis of the affected brain areas is quantified using ImagePro 2.1 software. Infarct volume is expressed as % of contralateral hemisphere. Statistical comparisons are made across treatment groups (one-way ANOVA).

Example 8

In Vivo Study: Transient Model of Cerebral Ischemia

Male Wistar rats (Iffa Cr do, France), weighing 250-300 g, were housed 2 per cage under a light-dark cycle of 12 hr - 12 hr (light on at 7:00 a.m., off at 7:00 p.m.) at a room temperature of $21\pm 2^{\circ}\text{C}$, with $50\pm 15\%$ humidity, for a minimum of 5 days before the experiments. During this time, the rats had free access to commercial rat chow (Trouw Nutrition France, Vigny, France, ref. 811002) and tap water.

The animals were anaesthetized with 5% halothane in air for induction, then 1-2% halothane during surgery. The rat's body temperature was maintained at 37°C with a heating pad. A 2cm incision was made at the center of the neck and the right common carotid artery (CCA), external carotid artery (ECA) and internal carotid artery (ICA) were exposed under an operating microscope. The ICA was further dissected to identify the pterygopalatine artery (PA) branch and the intracranial ICA branch. The CCA was ligated. A 3-0 silk suture was tied at the origin of the ECA and ligated. A catheter (id = 0.58 mm) was introduced into the CCA through a small puncture and advanced to the intracranial branch of the ICA. A 4-0 surgical nylon suture was gently advanced from the CCA into the lumen of the ICA until the suture blocked the origin of the MCA. The suture was sealed into the catheter by heat, leaving 1cm of catheter protruding so the suture could be withdrawn to allow reperfusion. The incision was closed using skin clips. Anaesthesia was then terminated and the animals were placed under heat lamps until recovery from anaesthesia. The rats awakened 10-15 min later. After 2 hr of ischemia, reperfusion was performed by withdrawal of the suture until the tip cleared the ICA lumen. Vehicle or test compound was administered intraperitoneally (i.p.) or intravenously (i.v.) at 1hr post ischemia onset.

24 h after the onset of occlusion, the rats were killed by decapitation. The brains were immediately removed, frozen in isopentane and stored at -20°C. The brains were then cut in 20 µm thick sections in a cryocut. Every 20th slice was used to measure infarct area. The sections were stained with cresyl violet and the areas of infarct in the striatum and cortex were determined by planimetry using an image analysis software (Image, NIH) after digitalization of the section images.

Following the procedure described above, MK-801, compound #46 and compound #264 (as listed in the Tables herein) were evaluated for neuroprotective effects in rats with results as listed in Table VIII. The data represent average lesion volume in mm³ for 12 measurements. Vehicle used was 15% solutol in 5% dextrose.

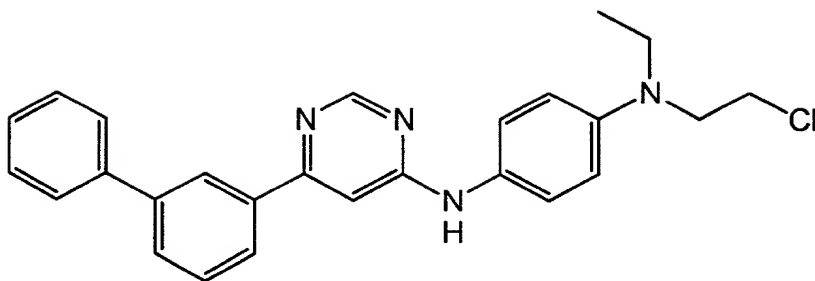
Table VIII
Effect of Compound #46 and Compound #264 in the transient model of cerebral ischemia in rats

<u>Test Compound</u> <u>(Admin. Amount)</u>	<u>Cortex Vol.</u> <u>(mm³)</u>	<u>Striatum Vol.</u> <u>(mm³)</u>	<u>Cortex + Striatum</u> <u>Vol. (mm³)</u>
Vehicle	236.3 ± 21.0	75.2 ± 2.5	311.6 ± 22.6
MK-801 (3 mg/kg, i.p.)	135.0 ± 26.1	70.4 ± 2.9	205.4 ± 28.0
Cmpd 46 (0.6 mg/kg, i.v.)	247.6 ± 24.8	79.1 ± 3.0	326.6 ± 26.0
Cmpd 46 (3 mg/kg, i.v.)	214.7 ± 26.6	76.1 ± 2.8	290.8 ± 28.1
Cmpd 264 (0.3 mg/kg, i.v.)	194.3 ± 33.9	72.1 ± 3.6	266.4 ± 35.4
Cmpd 264 (1.5 mg/kg, i.v.)	174.2 ± 30.5	72.4 ± 2.5	246.6 ± 31.0

Synthesis Examples

Example 9

N-(6-Biphenyl-3-yl-pyrimidin-4-yl)-N'-(2-chloroethyl)-N'-ethyl-benzene-1,4-diamine



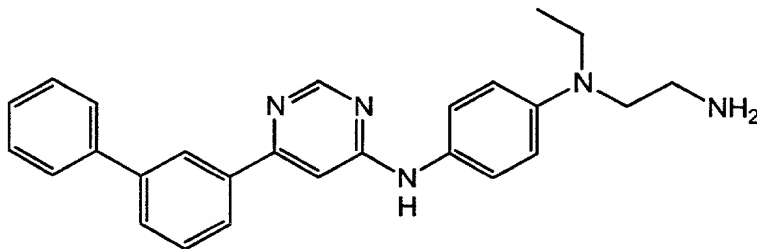
A solution of 2-([4-(6-biphenyl-3-yl-pyrimidin-4-ylamino)-phenyl]-ethylamino)-ethanol (2 g, 4.8 mmol) (available from BioFocus PCC (UK)) and dichloromethane (40 mL) was treated with thionyl chloride (1.4 mL, 19.1 mmol) and stirred overnight at room temperature. The reaction was quenched with NaHCO_3 (s) and extracted with dichloromethane. The organic layer was dried with MgSO_4 , filtered and evaporated to yield the title product as a crystalline solid.

Yield: (1.7g, 82%).

10

Example 10

N-(2-Aminoethyl)-N'-(6-biphenyl-3-yl-pyrimidin-4-yl)-N-ethyl-benzene-1,4,-diamine



A solution of N-(6-Biphenyl-3-yl-pyrimidin-4-yl)-N'-(2-chloroethyl)-N'-ethyl-benzene-1,4-diamine (0.35 g, 0.82 mmol) and N-methyl pyrrolidinone (5 mL) was treated with potassium phthalimide (0.227 g, 1.2 mmol) and the resulting mixture was stirred overnight at 100°C. The reaction was cooled, diluted with dichloromethane, and washed with water until the aqueous layer was neutral. The organic layer was dried over K_2CO_3 , filtered and the solvent evaporated to yield 2-(2-([4-(6-biphenyl-3-yl-pyrimidin-4-ylamino)-phenyl]-ethylamino)-ethyl)-isoindole-1,3-dione.

A solution of 2-(2-([4-(6-biphenyl-3-yl-pyrimidin-4-ylamino)-phenyl]-ethylamino)-ethyl)-isoindole-1,3-dione (0.5 g, 0.82 mmol), ethanol (50 mL) and hydrazine monohydrate (3 mL) was refluxed for 3 hours, and then stirred overnight at room temperature. After cooling to 0°C, concentrated HCl/water (1:1, 20mL) was added and the reaction was refluxed for 2 hours. The ethanol was evaporated and the

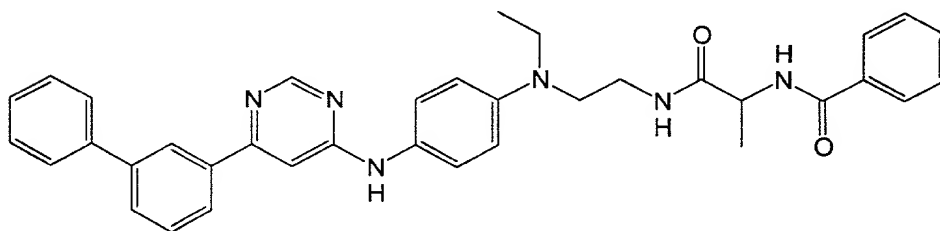
aqueous mixture was filtered. The filtrate was made basic with $\text{NaHCO}_3(\text{s})$ and was extracted with dichloromethane. The organic layer was dried with MgSO_4 , filtered and solvent evaporated to yield the title product as a solid.

Yield: (0.17 g, 51%).

5

Example 11

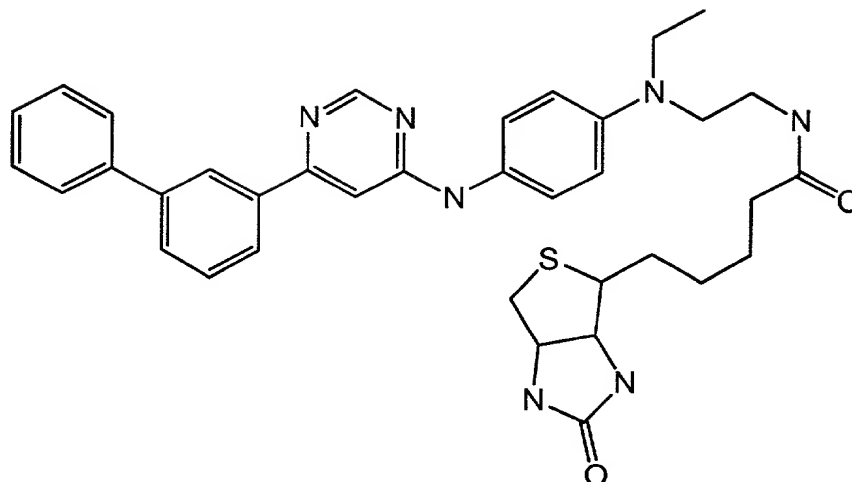
N-[1-(2-{[4-(6-biphenyl-3-yl-pyrimidin-4-ylamino)-phenyl]-ethyl-amino}-ethylcarbamoyl)-ethyl]-benzamide, Compound (205)



10 A solution of N-(2-aminoethyl)-N'-(6-biphenyl-3-yl-pyrimidin-4-yl)-N-ethyl-benzene-1,4,-diamine (0.1 g, 0.185 mmol), N-benzoyl-alanine (0.032 g, 0.185 mmol), diisopropylethylamine (DIPEA) (0.066ml, 0.37 mmol), HBTU (0.07 g, 0.185 mmol), and N,N-dimethylformamide (DMF) was stirred overnight at room temperature. Ethyl acetate and $\text{NaHCO}_3(\text{s})$ were added with vigorous stirring. The organic layer was dried
15 over Na_2SO_4 , filtered and evaporated to a solid. This material was purified by HPLC to yield the title compounds as an orange solid.

Example 12

20 5-(2-oxo-hexahydro-thieno[3,4-d]imidazol-6-yl)-pentanoic acid (2-{[4-(6-biphenyl-3-yl-pyrimidin-4-ylamino)-phenyl]-ethyl-amino}-ethyl)-amide, Compound (206)



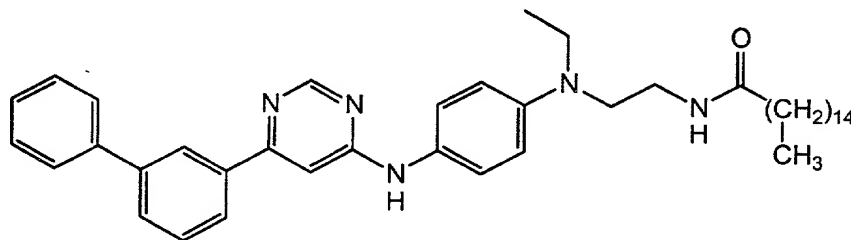
A solution of N-(2-Aminoethyl)-N'-(6-biphenyl-3-yl-pyrimidin-4-yl)-N-ethyl-benzene-1,4,-diamine (0.1 g, 0.24 mmol), biotin succinate ester (0.1 g, 0.29 mmol), DIPEA (0.2 ml), and dioxane was stirred overnight at room temperature. Ethyl acetate and water were added with thorough mixing. The organic layer was separated, dried over MgSO_4 , filtered and evaporated. The residue was purified by reverse phase chromatography to yield the title compounds.

Yield: (0.031g, 41%).

Compound 208 was similarly prepared according to the procedure outlined above with appropriate selection and substitution of reagents.

Example 13

Hexadecanoic acid (2-{[4-(6-biphenyl-3-yl-pyrimidin-4-yl-amino)-phenyl]-ethyl-amino}-ethyl)-amide, Compound (210)



A solution of N-(2-aminoethyl)-N'-(6-biphenyl-3-yl-pyrimidin-4-yl)-N-ethyl-benzene-1,4,-diamine (0.025 g, 0.06mmol), palmitoyl acid chloride (0.016 mL, 0.06 mmol), DIPEA (0.024 mL, 0.132 mmol), and dioxane (0.4 mL) was stirred at room temperature overnight. Ethyl acetate and $\text{NaHCO}_3(\text{s})$ were added with thorough

mixing. The organic layer was separated, dried over MgSO_4 , filtered and evaporated to an oil. This material was purified using reverse phase chromatography (20% $\text{CH}_3\text{CN}/\text{H}_2\text{O}$) to yield the title compound as a solid.

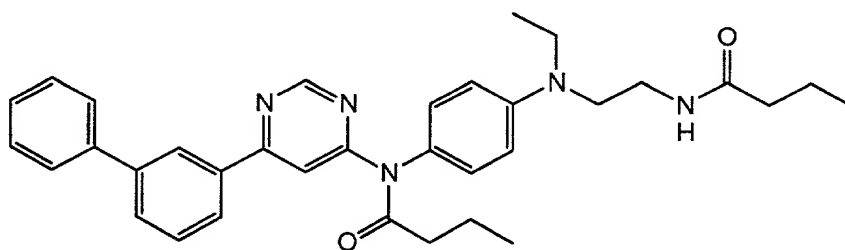
Yield: (0.011 g, 28%).

5

Compounds 207, 211, and 212 were similarly prepared according to the process outlined above with appropriate selection and substitution of reagents.

Example 14

10 N-(2-{[4-[(6-biphenyl-3-yl-pyrimidin-4-yl)-butyryl-amino]-phenyl]-ethyl-amino}-ethyl)-butyramide, Compound (274)



A solution of N-(2-aminoethyl)-N'-(6-biphenyl-3-yl-pyrimidin-4-yl)-N-ethyl-benzene-1,4,-diamine (0.025 g, 0.06mmol), propionyl chloride (0.006 mL, 0.06 mmol, 15 DIPEA (0.024 mL, 0.132 mmol), and dioxane (0.4 mL) was stirred at room temperature overnight. Ethyl acetate and $\text{NaHCO}_3(\text{s})$ were added with thorough mixing. The organic layer was separated, dried over MgSO_4 , filtered and evaporated to an oil. This material was purified using reverse phase chromatography (20% $\text{CH}_3\text{CN}/\text{H}_2\text{O}$) to yield the title compound as an oil.

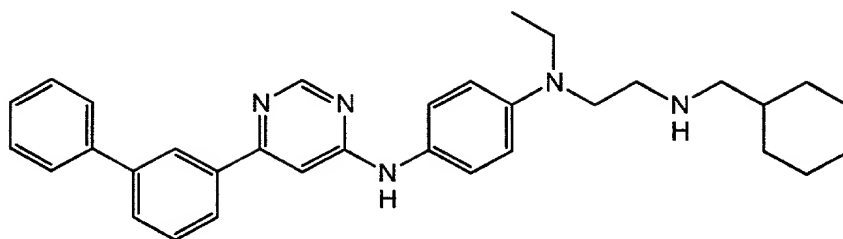
20 Yield: (0.012 g, 37%).

Compounds 272 and 273 were similarly prepared according to the process outlined above with appropriate selection and substitution of reagents.

25

Example 15

N-(6-biphenyl-3-yl-pyrimidin-4-yl)-N-[2-(cyclohexylmethyl-amino)ethyl]-N'-ethyl-benzene-1,4-diamine, Compound (214)



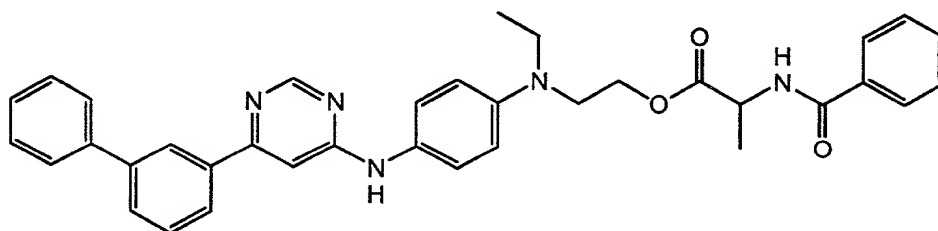
A solution of N-(6-biphenyl-3-yl-pyrimidin-4-yl)-N'-(2-chloroethyl)-N'-ethyl-benzene-1,4-diamine (0.025 g, 0.058 mmol), cyclohexylamine (0.022 mL, 0.174 mmol), and 1-methyl-2-pyrrolidinone (0.6 mL) was heated at 130°C overnight in a glass microtube. The reaction mixture was filtered and the product was separated from the filtrate via reverse phase chromatography (20% CH₃CN/H₂O) to yield the title product as an oil.

Yield: (0.002g, 7%).

Compounds 209, 213, and 215-269 were similarly prepared according to the process outlined above with appropriate selection and substitution of reagents.

Example 16

2-Benzoylamino-propionic acid 2-2-{[4-(6-biphenyl-3-yl-pyrimidin-4-yl-amino)-phenyl]-ethyl-amino}-ethyl ester, Compound (269)



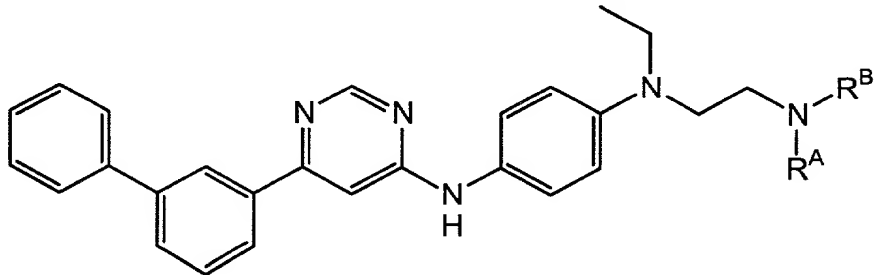
A solution of 2-{[4-(6-biphenyl-3-yl-pyrimidin-4-ylamino)-phenyl]-ethyl-amino}-ethanol (0.2 g, 0.37mmol), N-benzoylalanyl chloride (Berkowitz, et al. JOC, 60(5),1995, 1233) (0.6 mL, 1.9 mmol), and toluene (0.5 mL) was stirred at 80°C overnight. After the reaction was cooled, DMF (1mL) was added and stirring was resumed for 1 hour. Ethyl acetate and NaHCO₃(s) were added with thorough mixing. The organic layer was separated, dried over MgSO₄, filtered and evaporated to an oil. The material was purified via flash chromatography (20% methanol/CH₂Cl₂) to yield the title product as a solid.

Yield: (0.041 g, 19%).

Compounds 270 and 271 were similarly prepared according to the process outlined above with appropriate selection and substitution of reagents.

- 5 Following the procedures described above, representative compounds of formula (I) of the instant invention were prepared as listed in Tables IX, X, XI and XII.

Table IX: Representative Compounds of Formula (I)

		
Cmpd No.	R ^A	R ^B
204	H	H
209	Methyl	Methyl
213	H	Methoxypropyl
214	H	Cyclohexylmethyl
215	H	3-Chlorobenzyl
216	H	2,4-di-Methoxybenzyl
217	H	2-ethoxybenzyl
218	H	propyl
219	H	2,5-di-Fluorobenzyl
220	H	dehydroabietyl
221	H	Phenylethyl
222	H	3,4-di-Methoxybenzyl
223	H	Diethylaminopropyl
224	H	4-Bromo-2-pyridyl
225	Benzyl	Dimethylaminoethyl
226	Benzyl	n-butyl
227	H	4-biphenyl
228	H	2-furanylmethyl
229	H	3-Iodobenzyl
230	H	2,2,2-trifluoroethyl
231	H	3,4-di-Fluorobenzyl
232	H	2-thienylethyl
233	H	3,5-dimethyl-2-pyridyl
234	Benzyl	Phenylethyl
235	Benzyl	2-(ethoxy)acetyl
236	H	2-methoxybenzyl
237	H	4-Bromobenzyl

238	H	3,5-di-Trifluoromethylbenzyl
239	H	3-Methoxyphenylethyl
240	H	3,4,5-Trimethoxybenzyl
241	H	4-Methoxyphenylethyl
242	H	4-imidazolylethyl
243	H	2-Trifluoromethylbenzyl
244	H	benzyl
245	H	3-Methoxybenzyl
246	H	3-Methylbenzyl
247	H	3,5-Dimethoxybenzyl
248	H	2-Bromobenzyl
249	H	4-Bromophenethyl
250	H	4-Fluorobenzyl
251	H	1-Naphthylmethyl
252	H	Phenoxyethyl
253	H	4-Trifluoromethylbenzyl
254	H	n-butyl
255	Benzyl	benzyl
256	H	3-pyridyl
257	H	4-Trifluoromethylbenzyl
258	H	2-Methylbenzyl
259	H	3-Methylbenzyl
260	H	2-Fluorobenzyl
261	H	3,4-dimethoxyphenethyl
262	Ethyl	benzyl

Table X: Representative Compounds of Formula (I)

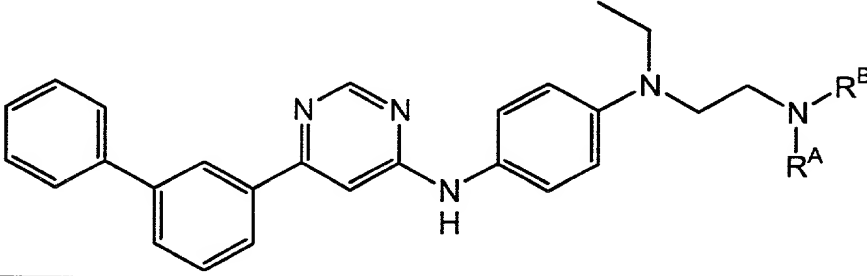
	
Cmpd No.	R ^A and R ^B taken together with the N atom
263	N-Pyrrolidinyl
264	N-Morpholinyl
265	N-Imidazolyl
266	N-1,2,3,4-Tetrahydroisoquinolinyl
267	N-Hexamethyleneimine
268	N-(4-Tertiarybutyloxycarbonyl)piperazinyl

Table XI: Representative Compounds of Formula (I)

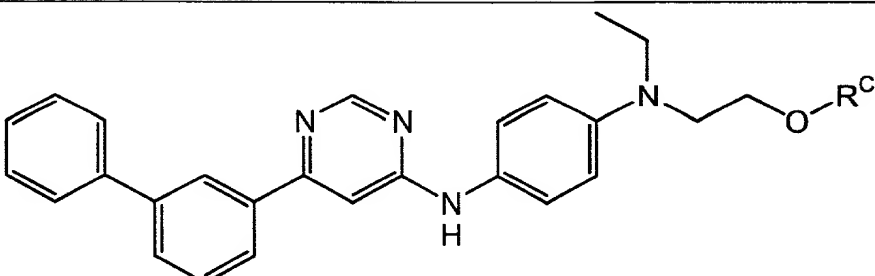
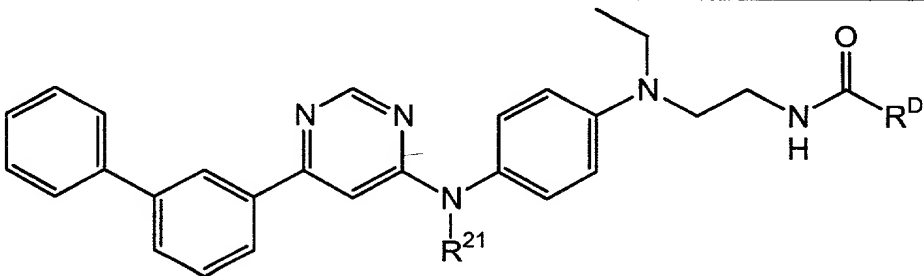
	
Cmpd No.	R ^c
269	(±)-N-Benzoyl)-2-aminopropionoyl
270	[3aS-(3α,4β,6α)]- Hexahydro-2-oxo-1H-thieno[3,4-d]imidazole-4-pentanoyl
271	Benzoyl

Table XII: Representative Compounds of Formula (I)

		
Cmpd No.	R ²¹	R ^D
205	H	(±)-N-Benzoyl)-aminoeth-2-yl
206	H	[3aS-(3α,4β,6α)]- Hexahydro-2-oxo-1H-thieno[3,4-d]imidazole-but-4-yl
207	H	1-Chloro-1-phenyl-methyl
208	H	3-azo-6-nitrophenyl
210	H	Pentacecanyl
211	H	4-Biphenyl
212	H	4-butoxyphenyl
272	4-trifluoromethyl phenylcarbonyl	4-trifluoromethylphenyl
273	3-fluorophenyl carbonyl	3-fluorophenyl
274	propylcarbonyl	propyl

The representative compounds listed in Tables IX< X, XI and XII were tested according to the procedure described in Example 5 with results as listed in Table XIII. Unless otherwise noted, molecular weights were measure on a Hewlitt-Packard Series 1050 Chemical Ionization mass spectrometer.

Table XIII: Measured Activity and Molecular Weights

Cmpd No.	ED ₅₀	MW Calc	MW Meas
204		409	410.2
205		584.7	585.4
206		635.8	636.4
207		562.1	562.2
208		599.7	600.2
209	0.0023	437.6	438.1
210		647.9	648.4
211		589.7	590.2
212		585.7	586.2
213	0.37	481.6	482.1
214	0.525	505.7	506.2
215	0.654	534.1	534.1
216	1.69	559.7	560.2
217	1	543.7	544.2
218	1.9	451.6	452.1
219	0.36	535.6	536.2
220	1	677.9	678.4
221	0.652	513.6	514.2
222	1.85	559.7	560.2
223	1.14	522.7	523.2
224	0.507	565.5	567.1 (M+2)
225	0.509	570.7	571.3
226	0.618	555.8	556.3
227	3.8	561.7	562.2
228	0.885	489.6	490.1
229	1.9	625.6	626.1
230	1.3	491.6	492.1
231	0.267	535.6	536.1
232	0.769	519.7	520.1
233		514.6	515.2
234	1	603.8	604.3
235	1	585.7	586.2
236	1.1	529.7	530.2
237	0.361	578.6	580.1(M+2)
238	1	635.7	636.1
239	0.606	543.7	544.2
240	0.285	589.7	590.2
241	1.25	543.7	544.2
242	1.28	503.7	504.1
243	1	567.7	568.2
244	0.43	499.7	500.1
245	1.6	529.7	530.2
246	0.118	513.7	514.2
247	1	559.7	560.2
248	1	578.6	581.1(M+2)
249	1	592.6	594.1(M+2)
250	1.8	517.6	518.2

251	1	549.7	550.2
252	0.523	529.7	530.2
253	2	583.7	584.2
254	0.483	465.6	466.2
255	1	589.8	590.3
256	1.6	500.6	501.2
257	1	567.7	568.2
258	1	567.7	568.2
259	0.394	513.7	514.2
260	2.3	517.6	518.2
261	1.6	573.7	574.3
262	1	527.7	528.2
263		506.7	507.2
264	0.002	522.7	523.2
265	1	460.58	461.1
266	1.2	525.7	526.2
267		505.7	506.2
268	0.5	578.8	579.3
269		585.7	586.4
270		636.8	637.3
271		514.6	515.1
272		409	410.2
273		584.7	585.4
274		521.7	522.1

While the foregoing specification teaches the principles of the present invention, with examples provided for the purpose of illustration, it will be understood that the practice of the invention encompasses all of the usual variations, adaptations and/or
5 modifications as come within the scope of the following claims and their equivalents.

References

- Ahn, N., et al. (1991) *J. Biol. Chem.* 266:4220-4227.
- Alessandrini, A., et al. (1999) *Proc Natl Acad Sci U S A* 96:12866-9.
- 10 Anderson, N., et al. (1990) *Nature* 343:651-653.
- Bading, H., Greenberg, M. E. (1991) *Science* 253:912-914.
- Callaway, J., et al. (1999) *Stroke* 12:2704-2712.
- Canzoniero, L., et al. J. (1996) *J. Neurosci. Res.* 45:226-236.
- Cheng, Y., et al. (1998) *J. Clin. Invest.* 101:1992-1999.
- 15 Chijiwa, T., et al. (1990) *J. Biol. Chem.* 265:5267-5272.
- Courtney, M., et al. (1990) *J Neurosci.* 10:3873-3879.

- Crews, C., Alessandrini, A., Erikson, R. (1992). *Science* 258:478-480.
- Desdouits-Magnen, J., et al. (1998) *J. Neurochem.* 70:524-530.
- Enslin, H., et al. (1996) *Proc Natl Acad Sci USA* 93:10803-10808.
- Favata, M. F., et al., (1998) *J. Biol. Chem.* 273:18623-18632.
- 5 Fiore, R. S., et al. (1993) *J Neurochem* 61:1626-1633.
- Grobin, A. C., (1999). *Brain Research* 827:1-11.
- Heath, D., Vink, R. (1999). *J. Neurosurg.* 90:504-509.
- Henry, J., et al. (1998) *J. Med. Chem.* 41:4196-4198.
- Hu, B., Wieloch, T. (1994) *J. Neurochem.* 62:1357-1367.
- 10 Inhorn, R., Majerus, P. (1987) *J. Biol. Chem.* 262:15946-15952.
- Ishii, T., et al. (1993) *J. Biol. Chem.* 268:2836-2843.
- Jaiswal, R., et al. (1994) *Mol. Cell. Biol.* 14:6944-6953.
- Jones-Velleneuve, et al. (1982) *J. Cell Biol.* 94:253-262.
- Jones-Villeneuve, et al. (1983) *Mol. Cell Biol.* 3:2271-2279.
- 15 Jovanovic, J., et al. (1996) *Proc. Natl. Acad. Sci. USA* 93:3679-3683.
- Kindy, M. (1993) *J Cereb Blood Flow Metab* 13:372-377.
- Kobayashi, E., et al. (1989) *Biochem. Biophys. Res. Commun.* 159:548-553.
- Kurino, M., et al. (1995) *J Neurochem* 65:1282-1289.
- Lander, H., et al. (1996) *J. Biol. Chem.* 271:19705-19709.
- 20 Laurie, D., et al. (1995) *Brain Res. Mol. Brain Res.* 32:94-108.
- Lee, J., et al. (1994) *Nature* 372:739-746.
- Lev, S., et al. (1995) *Nature* 376:737-745.
- Li, B., et al. (1999a) *Eur. J. Biochem.* 262:211-217.
- Li, M., et al. (1999b) *Brain Res.* 1999:44-52.
- 25 McBurney, M. W., et al. (1982) *Dev. Biol.* 89:503-508.
- Meldrum, B., Garthwaite, J. (1990) *Trends Pharmacol Sci* 11:379-387.
- Monyer, H., et al. (1994) *Neuron* 12:529-540.
- Monyer, H., et al. (1992) *Science* 256:1217-1221.
- Moodie, S., et al. (1993) *Science* 260:1658-1661.
- 30 Morley, P., et al. (1995) *J. Neurochem.* 65:1093-1099.
- Murray, B., et al. (1998) *Proc. Natl. Acad. Sci. USA* 95:11975-11980.
- Onoda, T., et al. (1989) *J. Nat. Prod.* 52:1252-1257.
- Papin, C., et al. (1995) *Oncogene* 10:1647-1651.

- Park, C., et al. (1988) *Ann. Neurol.* 24:543-551.
- Pazos, A., et al. (1999) *Brain Res.* 846:186-195.
- Pleasure, S., Lee, V.-Y. (1993) *Journal of Neurosci. Res.* 35:585-602.
- Pleasure, S., et al. (1992) *J. Neurosci.* 12:1802-1815.
- 5 Ray, W. J., Gottlieb, D. I. (1993) *Biochem. Biophys. Res. Comm.* 197:1475-1482.
- Rootwelt, T., et al. (1998) *J. Neurochem.* 71:1544-1553.
- Rosen, L., et al. (1994) *Neuron* 12:1207-1221.
- Sakagami, H., Kondo, H. (1993) *Brain Res Mol Brain Res* 19:215-218.
- Sakakibara, Y., et al. (2000) *Neurosci Lett* 281:111-114.
- 10 Sattler, R., et al. (1999) *Science* 284:1845-1848.
- Schneggenburger, R., et al. (1993) *Neuron* 11:133-143.
- Schwartz-Bloom, R., et al. (1998) *J Cereb Blood Flow Metab* 18:548-558.
- Sola, C., et al. (1999) *J Neurosci. Res.* 57:651-652.
- Stanciu, M., et al. (2000) *J. Biol. Chem.* 275:12200-12206.
- 15 Standaert, D., et al. (1994) *J. Comp. Neurol.* 343:1-16.
- Takahashi, M., et al. (1998) *J. Pharmacol. Exp. Ther.* 287:559-566.
- Tatlisumak, T., et al. (1998) *Stroke* 29:1952-1958.
- Tokumitsu, H., et al. (1990) *J. Biol. Chem.* 265:4315-4320.
- Turetsky, D. M., et al. (1993) *J. Neurobiol.* 24:1157-1169.
- 20 Turski, L., et al. (1998) *Proc. Natl. Acad. Sci. USA* 95:10960-10965.
- Tymianski, M., et al. (1993) *J. Neurosci.* 13:2085-2104.
- Vanhoutte, P., et al. (1999) *Mol. Cell. Biol.* 19:136-146.
- Wasterlain, C., et al. (1996) *Stroke* 27:1236-1240.
- Xia, Z., et al. (1995) *Science* 270:1326-1331.
- 25 Xia, Z., et al. (1996) *J. Neurosci.* 16:5425-5436.
- Yang, D. D., et al. (1997) *Nature* 389:865-870.
- Yang, Y., et al. (1998) *Brain Res.* 804:169-176.
- Zheng, C., et al. (1993) *J. Biol. Chem.* 268:23933-23939.